LUNAR CORE DRILL

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ABSTRACT

This report presents a unique design of a core drilling mechanism which could be used on the moon to collect rock cores to depths of 100 feet below the surface. The design is necessarily unique due to the fact that the moon has virtually no atmosphere and only one-sixth the gravity of earth. These adverse conditions require certain important concepts to be included in the design. The most notable of these concepts are:

1. The complete use of hydraulic power to operate the device;

2. The use of Teflon beads to cool the bit and remove the chips;

3. The use of extensive automation to reduce the dexterity requirements of the astronauts.

In addition, the actual drilling force will be transmitted by a robot arm that functions much like a backhoe. Thus, with a bucket or digging attachment it would be possible to use the arm in two ways: either as a core drilling mechanism or as a lunar excavator. The major topics discussed in this report include the following:

1. Arm design;

2. Drill motor, drill string, core barrel and bit, core retriever, and footplate;

3. Pumping system for cooling and chip removal;

4. Hydraulic power system and electrical controls.

PROBLEM STATEMENT

Basic Statement: The problem is to design a core drill for use on the moon wiich can be operated by astronauts efficiently and will reliably obtain intact core samples from depths of 100 feet. Ideally, the core drill is to be capable of pivoting 180 degrees in a horizontal plane and coring a hole at any angle within the range of -90. to 90. degrees woth respect to vertical.

Backround: Core drilling is frequently done on earth to aid in evaluating the underground geological properties of sites being considered for construction or mining purposes. Analyzation of the core can provide the geologist with much important information concerning the formation of the underground rock, the strength, and the compostion--all fo which aides the engineer in deciding how best ot use a particular site. Thus, core drilling is common, and, having been practiced for many years, is technologically sound on earth.

However, it is not feasible to handle core drilling on the moon in exactly the same manner as it is handled on earth. The fact that the moon has virtulally no atmosphere and only one-sixth the gravity of earth gives rise to two basic difficulties concerning lunar core drilling which are unaccounted for in earth core drilling technology. These two basic difficulties are as follows:

1. **Lubrication:** Water or mud is used as a lubricant and chip remover for core drills on earth. However, because the moon has no atmosphere, water evaporates rapidly and thus cannot be used as a lubricant. A nonvaporizing lubricant, possibly solid Teflon beads, is necassary in a lunar design.

2. **Automation:** On earth, much of the work involved in core drilling requires an average amount of manual labor and physical dexterity. On the moon, however, the physical dexterity of astronauts is limited due to the bulky space suits and the low level of lunar gravity. Thus, a lunar core drill needs to be highly automated in order to be operated efficiently by the "handicapped" astronauts.

One other major difficulty concerns the range of motion required for this particular lunar core drill design. Core drills on earth are not made to function similar to backhoes and are not mormally designed to meet the angular requirements of this particular lunar design. Therefore, the decision to design the drilling mechanism similar to a backhoe linkage represents a step into delicate and untested technology.

Aside for the three major difficulties discussed above, the lunar core drill will be able to function in much the same was as an earth core drill. An abundance of information is available on the subject of earth core drilling and several large companies produce core drilling equipment which they offer commercially. Many of these commercially available assemblies, such as the drill motor, drill string, drill bit, core barrel, core retrieval mechanism, and breakout tool can be used effectively in a lunar design without difficult modifications.

Performance Objectives and Constraints: The following performance objectives and constraints for the core drilling mechanism served as guidelines during the design process. Many of the objectives and constraints remained unchanged throughout the course of the design period; however, slight modifications were made, and these modificatons are noted below in parentheses.

A. **Transmission of Drilling Force**:
   1. Transmission device to be a robotic arm, similar to a backhoe;
   2. Arm to have a 5' to 6' linear stroke;
   3. Arm to be capable of linear stroke at angles ranging from -90. to 90. with respect to vertical. (objective later changed to include only angles form -45. to 45. with respect to vertical;
   4. Base of main arm to be connected to tractor by way of a single pivot which is to rotate 180. in a horizontal plane;
   5. Arm to be hydraulically operated;
   6. Maximum force transmitted to be $\geq$ 8000 lbf in hole.

B. **Drill Motor**:
   1. Motor to be hydraulically operated and reversible;
   2. Motor to be variable speed, capable of 1200 rpm.

C. **Drill String**:
   1. Total string to read 100 feet;
   2. String to accept wireline overshot for core retrieval.

D. **Core Barrel and Bit**:
   1. Barrel to hold 5' core;
   2. Core barrel keep core separated from lubrication fluid in hole;
   3. Core barrel to accept wireline overshot for core retrieval;
   4. Diamond drill bit to be capable of cutting continuously through at least 100 ft of very hard basalt.

E. **Core Retriever:**

1. Wireline overshot to be retractable;
2. Wireline overshot to be of such a design that it can be forced down hole if necessary;
3. Wireline overshot to retrieve 5' core intact;
4. Winch to be used in raising and lowering overshot;
5. Winch to be hydraulically powered.

F. **Foot Plate:**

1. Foot plate to clamp and hold string in hole while new string secton is readied for assembly.
2. Foot plate to be used as a "break out" tool when necessary;
3. Foot plate to be capable of making angles ranging from -90. to 90. with respect to vertical. (Objective later changed to include only angles from -45. to 45. with respect to vertical.)

G. **Lubrication and Pumping System:**

1. Lubricant to be nonvolitale in absence of atmosphere;
2. Lubricant to be capable of both cooling drill bit and removing chips;
3. Lubricant to be separated from chips;
4. Lubricant to be reused continuously in closed loop;
5. Pump to be hydraulically powered.

H. **Hydraulic Power System and Electrical Controls:**

1. Hydraulic system to operate at or below 2500 psi and 25 gpm;
2. Electrical controls to operate at or below 24 VDC and 70 amps;
3. Control valves to precisely regulate hydraulic fluid flow to linear actuators on robot arm.

DETAILED DESCRIPTION

Arm Design: Determining a kinematically feasible configuration for the robot arm was a difficult task. Several different designs were evaluated before a satisfactory solution was found. In order to make the arm functional, it was necessary to reduce its angular range of motion. The final design, then, consists of a 3-bar, hydraulically operated backhoe type arm which is capable of swinging 180. in a horizontal plane, but, compromisingly, can produce a six foot linear stroke at <u>reduced</u> angles ranging only from -45. to 45. with respect to vertical. The maximum drilling force which can be exerted by the design is 8000 lbf.

The reduced angular range of the design reflects the modification made to an original performance objective which had required the mechanism to produce linear strokes at angles ranging from -90. to 90. The reduction in angular range, from -90. to 90. to -45. to 45., was made because of two important reasons: 1.) the commercially available break out tool selected for use in the design will not accomodate holes drilled at angles ranging form more that -45. to 45. with respect to vertical, and 2.) hydraulic cylinders with the required bore and stroke dimensions necessary for reliable use in a design which would satisfy the original angle performance objective are not commercially available.

Specific information concerning the final arm design is as follows:

Dimensions, Forces, Moments, and Angular Range
of Final Arm Design
(See drawings no. 101-121 in Appendix)

Effective link lengths of drilling mechanism:

Arm	Effective Link Length
Boom arm	8 ft.
Middle arm	4 ft.
Drill arm	2 ft.

Maximum Joint Moments created by the 8000 lbf drilling force and the required hydraulic forces necessary to balance such moments:

Joint	Max. Moments	Hyd. Bal. Force Req.
Boom joint	63,030 ft.lbf	64,700 lbf
Middle joint	6,874 ft.lbf	7,270 lbf
Drill joint	8,000 ft.lbf	2,110 lbf

Quantity, bore size, stroke length, and force capacties of hydraulic cylinders determined using a factor of safety of 1.5):

Cylinders*	Quantity	Bore Size	Stroke Length	Total Force
Boom arm	2	5"	40"	98,000 lbf
Mid. arm	1	3"	40"	17,650 lbf
Drl. arm	1	2"	20"	7,850 lbf

*note: All cylinders are double-acting.

The robot arm will be capable of drilling a 45. hole inward (toward) the tractor at a distance of 3' from the base of the boom arm. It wll be capable of drilling a 45. hole outward (away from) the tractor at a distance of 12 1/2' from the base of the boom arm. Other angles within the 90. range (45. inward, 45. outward) may be drilled at spots between 3' and 12 1/2' from the base.

Auxiliary Arm

(See Drawing no. *100* in Appendix)

A separately controllable auxiliary arm is designed to work in conjunction with the main arm outlined above. The auxiliary arm's function is to aide in the automatic assembly and disassembly of string sections. The auxiliary arm is attached to the middle link of the main arm and is designed with a hydraulically operated clamp on its free end. During the assembly and disassembly of the drill string, the auxiliary arm will be used to carry each successive section to or from a core tube rack and hold it firmly in place to be screwed or unscrewed from the drill head. The auxiliary arm is considered necessary to reduce the physical demands on the astronauts.

Dimensions and Hydraulic Cylinder Requirements of Auxillary Arm:

Effective Link Lengths of Auxillary Arm:

Arm:	Effective Link Length:
Arm #1	ft.
Arm #2	ft.

Quantity, bore size, stroke length, and force capacities of cylinders:

Cylinders*	Quantity	Bore Size	Stroke Length	Total Force
Arm #1	1	2"	12"	7,854 lbf
Arm #2	1	2"	10"	7,854 lbf

*note: All cylinders are double acting.

The boom arm is designed to be attached to the tractor by means of a swing pivot assembly. The swing pivot assembly is to be attached to the tractor by means of a vertical plate and is to be capable of rotating through an angle of 180. in a horizontal plane. When connected to the swing pivot mechanism, the base of the boom arm is to be 3' above the ground.

General Comments: The final arm design was determined after much graphical evaluation of several possible solutions. Various constraints were used as different times to simplify the decision making processes involved. Contraints that were considered were: 1.) requiring that it be possible to drill the full range of angles at a single spot, 2.) requiring the middle joint of the arm to start from the same point for all possible linear strokes, 3.) requiring all drilled holes to be as close as possible to the base of the boom arm (to reduce movements), 4.) restricting the angular movement of each of the linkages of the arm (to reduce hydraulic cylinder stroke requirements). Not all of the constaints lead to a feasible solution for the design of the arm. In the end, the constraint which seemed the most practical was the one which limited the angular ranges of motion of the linkages. With this constrain in mind, the final design (as it now stands) was developed.

Drill String Assembly: The drill string assembly consists of 6 major parts: the drill head, the sub, the drill rods, the reaming shell, the core barrel assembly and the bit.

The drill head assembly converts hydraulic power into rotational motion to turn the drill rods and bit. A Longyear Hydra-Core 28 drill head is attached to the manipulator arm. It is hydraulically powered (2500 psi, 25 gpm) and comes with a 4 speed (including reverse) transmission that provides a bit speed range of 0 to 1250 rpm. The turning pin is size BQ; therefore, a BQ to NQ sub is necessary. The drill haed assembly also contains a swivel for lubrication flow.

A series 6 RED impregnated diamond bit is used. The bit selected is recommended for hard rock formations when using a hydrostatically powered drill head. Recommended bit speed, down hole pressure, and penetration rate are 100-1200 rpm, 6000-8000 lbf, and 3-4 inches per minute, respectively. The bit connects to a reaming shell with a circumferential diamond impregnated flange which cuts a clearance for the core barrel. The core barrel is connected to the reaming shell and the drill rods.

Foot Plate Assembly: The foot plate assembly lies over the drill hole on the moon surface. Its three major functions are:

1. Stabilizing and aligning the drill rods.

2. Chucking the break-out drill rod when removing string pieces for dissembly or bit change.

3. Directing lubricant flow from the hole.

The first two of these are controlled by a pre-torque and break-out tool. It contains two sets of hydraulically actuated jaws that grip and rotate the drill rods. Lubrication flows through a sleeve assembly. This assembly is a 2 foot NW size casing attached to a side feed discharge swivel.

The footplate is a 4 foot by 4 foot by 1 inch plate of 2024 aluminum with a 6 inch by 24 inch clearance hole. A 35 inch long, 9 inch aluminum channel is welded on each side of the clearance hole. The pre-torque and break-out tool is bolted to the top of the channels to allow for positioning of the swivel assembly. The swivel assembly is bolted to the bottom of the foot clamp of the break-out tool by the swivel attachment pieces which are welded to the side discharge swivel.

This configuration is only appropriate for holes up to 45 degrees from vertical.

Core Retrieval: Since core samples may have to be retrieved from an angle, a pump-in type system will be utilized. This system consists of an overshot, side feed water swivel, a wireline stuffing box, and a hydraulic winch. The sub and head are removed from the rod and an Acker pump-in type "A" wire line overshot is inserted into the drill rod.

An Acker Side Feed water swivel is then attached to the drill rod. The swivel is preattached to a Mathey wire line stuffing box. The overshot cable runs through the stuffing box to a PullMaster PL-2 planetary hydraulic winch. This winch was chosen because it is totally enclosed, and the heat generated by the disc brake is dissipated by the hydraulic fluid of its motor.

Once the swivel is connected to the drill rod, pumping is resumed and the overshot moves down the drill string until it locks into the core barrel inner tube. Pumping is stopped, and the core is elevated by the winch. The swivel is disconnected from the drill rod, and the overshot and corebarrel are removed from the drill rod.

Pumping system for cooling and chip removal: In designing a lubrication system for a lunar core drilling apparatus, several factors had to be considered. Two of these are the low pressure atmosphere and the extreme temperature variations. On earth, water is the popular coolant and means of extracting the shavings from the bottom of the hole. The water is pumped down the center of the string, mixes with the shavings, and rises along the outside of the tube until it reaches the surface. However, the low lunar pressure would instantly vaporize the water: this was the first design problem.

While searching for an alternative substance, the extreme temperature variations must be kept in mind. As a solution to this problem, two possibilities were investigated. These were a silicone based oil and teflon beads. The beads were selected because of the chance of vaporization of the oil. Teflon has a high maximum operating temperature (500 degrees Fahrenheit) and will not gel at the low nighttime temperatures.

Because of the selection of the teflon beads, alternate equipment is required to handle the process. First, the pump must be able to transfer solids, therefore a progressing cavity pump was chosen. Another advantage of this pump is the continuous pushing action which provides minimum pulsation. Second, a process must be designed to enable the reuse of the beads. To solve this problem, an existing centrifugal cone filter was used. This filter forces the beads to the outside of the tank while the heavier shavings drop to the ground.

The pumping cycle begins with the pump pushing the teflon beads down the center of the string. Once reaching the bottom, the beads move outward through openings in the drill bit. This action permits the sweeping of the shavings out, up, and away from the drilling interface. As the mixture rises so does the heat. This is because 80% of the heat generated by drilling remains in the chips. This continuous process cools, cleans, and lubricates the system. Once the mixture reaches the surface, it is piped through the filter where the heated shavings are removed. The beads are passed onto the pump and the procedure continues.

Control System: The control system for the core drill unit consists of two parts: electrical and hydraulic. The electrical system is used for feedback signal processing, while the hydraulic system is used to move the actuators. A description of each system follows.

The heart of the electronic control system is a microprocessor (μP) or a programmable logic array (PLA). The choice between these two controllers would depend upon production quantities, with the PLA being more economical for large production runs. Typical operation of the electrical system involves processing of feedback information from the linear variable differential transformers (LVDT) located on each hydraulic cylinder. These sensors provide position and velocity information so that the controller may direct the drilling operation without the complexity of a vision system. The processor wses the difference between the known output and the feedback input to provide accurate closed-loop control. Also taken into account is the tractor orientation with respect to the vertical. Drill speed and direction of th rotation are controlled with a similar closed-loop feedback design.

The hydraulic system provides the muscle of the core drill unit. The double acting cylinders on the arms are controlled by Moog Model 642 3-way electrohydraulic servo valves. These valves allow precise control of the linear actuators. The drill motor and gripper are also controlled by valves of this type. Pressure reduction is accomplished with B&G,Ltd. pressure reduction units.

Communication/control by astronaut/operators is accomplished with a 2-way radio link. Feedback of all system parameters is available to the astronaut, and control parameters are entered as directed by the system. Drilling, lubrication, and bit-changing are controlled by system software, while breakout operations are manual due to their complexity. The entire system could be fully automated with further design time.

COMPLETE SYSTEM COST ANALYSIS

1. ARM ASSEMBLY		
	MATERIAL COST	$20,650.00
	DEVELOPMENT COST	$22,000.00
2. DRILLING ASSEMBLY		
	MATERIAL COST	$20,659.00
	DEVELOPMENT COST	$17,500.00
3. CORE RETRIEVAL SYSTEM		
	MATERIAL COST	$2,069.00
	DEVELOPMENT COST	$6,500.00
4. LUBRICATION SYSTEM		
	MATERIAL COST	$5,145.00
	DEVELOPMENT COST	$15,000.00
5. CONTROL SYSTEM		
	MATERIAL COST	$44,505.00
	DEVELOPMENT COST	$13,000.00
		============
TOTAL COST		$167,028.00

ARM COST ANALYSIS

QTY	DESCRIPTION	MATERIAL COST	LABOR HOURS	LABOR COST	TOTAL COST
1	POST PIN	$50.00	25.0	$1,250.00	$1,300.00
1	TRACTOR MTG PLATE	$180.00	20.0	$1,000.00	$1,180.00
1	PIN CAP	$40.00	15.0	$750.00	$790.00
1	OUTRIGGER ASSY	$150.00	30.0	$1,500.00	$1,650.00
2	SWING PLATE	$100.00	5.0	$250.00	$700.00
1	GRIPPER	$20.00	5.0	$250.00	$270.00
1	BOOM ARM	$400.00	25.0	$1,250.00	$1,650.00
1	MIDDLE ARM	$150.00	15.0	$750.00	$900.00
1	DRILL ARM	$80.00	9.0	$450.00	$530.00
1	AUX ARM # 1	$80.00	9.0	$450.00	$530.00
1	AUX ARM # 2	$100.00	12.0	$600.00	$700.00
5	SWING PINS	$20.00	15.0	$750.00	$3,850.00
2	5" BORE X 40" STROKE	$2,000.00	0.0	$0.00	$4,000.00
1	3" BORE X 40" STROKE	$1,000.00	0.0	$0.00	$1,000.00
1	2" BORE X 20" STROKE	$600.00	0.0	$0.00	$600.00
1	2" BORE X 12" STROKE	$400.00	0.0	$0.00	$400.00
2	2" BORE X 10" STROKE	$300.00	0.0	$0.00	$600.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
	TOTALS	$5,670.00	185.0	$9,250.00	$20,650.00

DEVELOPMENT COST	$22,000.00
TOTAL ARM COST	$42,650.00

DRILLING ASSEMBLY COST ANALYSIS

QTY	PART DESCRIPTION	MATERIAL COST	LABOR HOURS	LABOR COST	TOTAL COST
1	BREAK OUT TOOL	$9,750.00	0.0	$0.00	$9,750.00
1	FOOT PLATE	$150.00	8.0	$400.00	$550.00
1	DISCHARGE SWIVEL	$425.00	2.0	$100.00	$525.00
2	SWIVEL ATTACHMENT	$30.00	3.0	$150.00	$180.00
1	DRILL CASING	$47.00	0.0	$0.00	$47.00
20	DRILL RODS	$78.00	0.0	$0.00	$78.00
1	CORE BARREL	$1,265.00	0.0	$0.00	$1,265.00
1	REAMING SHELL	$230.00	0.0	$0.00	$230.00
1	DIAMOND BIT	$435.00	0.0	$0.00	$435.00
1	BQ to NQ SUB	$99.00	0.0	$0.00	$99.00
1	DRILL HEAD	$7,500.00	0.0	$0.00	$7,500.00
	TOTALS	$20,009.00	13.0	$650.00	$20,659.00

DEVELOPMENT COST	$17,500.00
TOTAL COST OF DRILLING ASSY	$38,159.00

CORE RETRIEVER COST ANALYSIS

QTY	PART DESCRIPTION	MATERIAL COST	LABOR HOURS	LABOR COST	TOTAL COST
1	OVERSHOT	$615.00	0.0	$0.00	$615.00
1	SWIVEL	$443.00	0.0	$0.00	$443.00
1	STUFFING BOX	$183.00	0.0	$0.00	$183.00
1	DERRICK	$298.00	0.0	$0.00	$298.00
1	STEEL CABLE	$150.00	0.0	$0.00	$150.00
1	WINCH	$380.00	0.0	$0.00	$380.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
	TOTALS	$2,069.00	0.0	$0.00	$2,069.00

DEVELOPMENT COST	$6,500.00
TOTAL COST OF DRILLING ASSY	$8,569.00

LUBRICATION SYSTEM COST ANALYSIS

QTY	PART DESCRIPTION	MATERIAL COST	LABOR HOURS	LABOR COST	TOTAL COST
1	PUMP	$3,800.00	0.0	$0.00	$3,800.00
1	PIPE	$25.00	2.0	$100.00	$125.00
1	PIPE	$30.00	2.5	$125.00	$155.00
1	CONE FILTER	$369.00	0.0	$0.00	$369.00
1	SILT POT	$281.00	0.0	$0.00	$281.00
3	SWIVEL HOSES	$130.00	0.0	$0.00	$390.00
1	COUPLING	$25.00	0.0	$0.00	$25.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
				$0.00	$0.00
	TOTALS	$4,660.00	4.5	$225.00	$5,145.00

DEVELOPMENT COST	$15,000.00
TOTAL COST OF DRILLING ASSY	$20,145.00

CONTROL SYSTEM COST ANALYSIS

QTY	PART DESCRIPTION	MATERIAL COST	LABOR HOURS	LABOR COST	TOTAL COST
7	MOOG MODEL 642 VALVES	$430.00	0.0	$0.00	$3,010.00
1	B&G PRESSURE REDUCER 3PS	$169.00	2.0	$100.00	$269.00
1	B&G PRESSURE REDUCER 7PS	$155.00	2.5	$125.00	$280.00
140	VICKERS HYD HOSE	$12.00	0.0	$0.00	$1,680.00
64	CONNECTORS	$2.10	0.0	$0.00	$134.40
7	LVDT SENSOR	$30.00	0.0	$0.00	$210.00
6	QUICK DISCONNECT	$25.00	0.0	$0.00	$150.00
3	ANGULAR SENSOR	$24.00	0.0	$0.00	$72.00
1	TRANSMITTER/RECEIVER	$9,000.00		$0.00	$9,000.00
1	COMPUTER CONTROLLER	$16,000.00		$0.00	$16,000.00
1	SOFTWARE	$1,200.00	250.0	$12,500.00	$13,700.00
	TOTALS	$27,047.10	254.5	$12,725.00	$44,505.40
	DEVELOPMENT COST				$13,000.00
	TOTAL COST OF DRILLING ASSY				$57,505.40

HAZARD AND FAILURE ANALYSIS

The robot arm is to be, for the most part, automatically controlled. Thus, the astronauts should not be required to exert themselves excessively or dangerously while operating it. However, the astronauts must take care to ensure that the arm is controlled properly.

The possibility does exist that the drill system will malfunction. For example, the auxiliary arm may be ineffective or inoperative, thereby forcing the astronauts to do more manual labor. In addition, the main arm could bend or break or become severely out of alignment due to excessive stress or poor control. Such a malfunction could cause hydraulic fluid to leak or spew and could possibly injure astronauts in the vicinity. Therefore, it is recommended that the astronauts operate the arm by remote control from a safe distance. Drilling should be stopped whenever it becomes necessary for the astronauts to closely inspect or work with the machine.

There are three major areas where failure can occur in the drill string: hydraulic failure, loss of coolant down the hole and mechanical failure of some part of the drill string. A loss of hydraulic pressure will result in decreased motor speed and a loss of coolant to the motor causing it to overheat. This, however, is easily detected and drilling can be stopped before serious damage is done to the equipment. A pressure alarm or indicator gauge would decrease the likelihood of such an accident.

A mechanical failure down hole could be very serious. A broken or badly worn bit or rod would be very difficult and time consuming to repair. For such an occasion, certain fishing tools such as a rod, shell, and bit recovery taps should be included in the equipment taken to the moon.

The loss of lubricant down hole is a serious problem. It both cools the bit and removes the chips generated by drilling. If the lubricant flow is restricted or cut off, frictional heat and chips build up causing large mechanical and thermal stresses in the bit and rods. This sort of failure could result in the loss of the bit, reamer shell, and core barrel.

The core retrieval system is also subject to failure. This system can fail if the overshot will not lock onto the core barrel or if the cable snaps during hoisting. If this occurs the overshot should be hoisted up and reinserted, if this still fails the string will have to be dismantled to retrieve the core.

OPERATING INSTRUCTIONS

1. Site Preparation
   a. Clear lose and broken rock.
   b. Drill starter hole at desired angle, 2' X 3.5"dia.
   c. Insert swivel sleeve into hole.
   d. Set breakout tool angle and position over hole such. that swivel attachment holes are in line.
   e. Attach swivel.
   f. Position drill arm, rod rack, pumps, and derrick.
   g. Attach hydraulic lines.

2. String Preparation
   a. Attach bit, reamer shell and core barrel.
   b. Lift assembly with auxiliary arm and insert it into the breakout tool.
   c. Lower until one half foot of barrel remains over tool, then chuck the barrel.
   d. Release auxiliary arm.

3. Drilling
   a. Lift and position drill rod.
   b. Connect drill head to drill rod and drill rod to to section remaining above the breakout tool.
   c. Start lubrication flow.
   d. Unchuck the rod.
   e. Start drill motor and drill for the 5 foot stroke.
   f. Stop drilling.
   g. Chuck rod in place.
   h. Stop lubrication flow.
   i. Empty chip pot.
   j. Detach drill head.
   k. Move arm up.

4. Core Retrieval Procedure
   a. Use auxiliary arm to position and insert the overshot into the drill rod.
   b. Lower the overshot as far as possible. (If overshot lowers enough to lock onto core barrel the following steps are not necessary.)
   c. Attach the swivel/stuffing box assembly to drill rod.
   d. Start pumping lubricant, until overshot locks onto core barrel.
   e. Stop pumping lubricant.
   f. Detach swivel/stuffing box assembly.
   g. Hoist core up and out of the drill string.
   h. Grasp core barrel with auxiliary arm.
   i. Disconnect overshot from core barrel.
   j. Raise overshot and swivel/stuffing box assenbly out of the way.

k. Remove core from core barrel and place it into core box.
l. Return core barrel to drill string and lower it. (or continue with Step 6)

5 Repeat steps 3 and 4 until desired drilling depth is obtained.

6. Drill String Dissembly
   a. Connect drill head to drill rod.
   b. Unchuck drill rod.
   c. Raise the string five feet.(First rod only raise 2 feet)
   d. Use foot clamp to hold drill rod.
   e. Use break out tool to break out drill rods.
   f. Unclamp drill rod.
   g. Lift string five more feet.
   h. Clamp drill rod.
   i. Disconnect top drill rod using auxiliary arm.
   j. Return rod to the rack.
   k. Connect drill head to top drill rod.
   l. Repeat steps 6e. thruogh 6h. until all drill rods are removed.
   m. Remove core barrel, reamer shell, and bit from last tube.
   n. Reverse steps 1a. through 1g. to dissemble site equipment.

CONCLUSIONS AND RECOMMENDATIONS

The proposed lunar core design contains several interesting innovations and deserves further study. In particular the three areas that require the most attention are: 1) arm design, 2) Teflon bead lubrication, and 3)automation.

Arm Design

Having a robotic arm similiar to a backhoe in the design of the lunar core drill is very interesting and certainly practical in the sense that the arm can be used both for core drilling and for lunar excavation. However, the hydraulic forces required to operate such a dual purpose arm are extremely high and border on impracticality. Possible kinematic improvements on the design of the arm need to studied extensively.

Teflon Beads

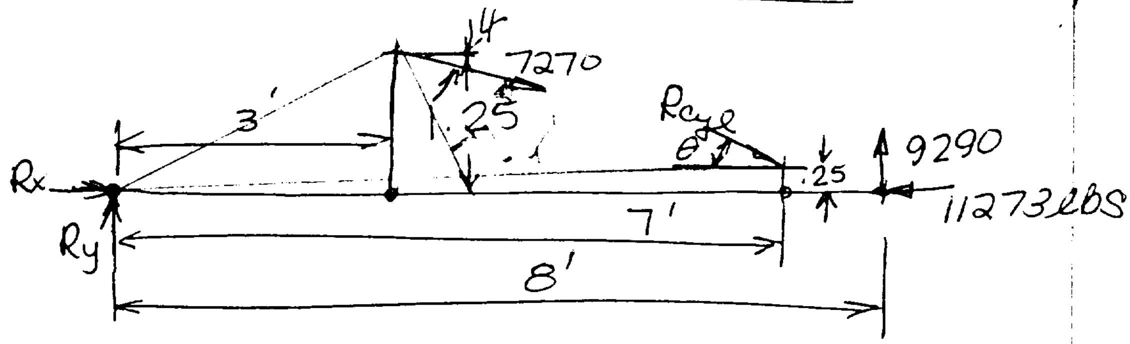
Using Teflon beads for lubrication, cooling, and chip removal is an extremely promising idea, but also untested. Experimentation is necessary to properly evaluate the effectiveness of the beads. In addition, further consideration needs to be given to the possible drawbacks of the Teflon beads; namely: 1) Unwanted smearing of the hole with a thin Teflon film, 2) difficulty in efficiently separating the beads from the chips, 3) difficulty in removing the beads from the hole once drilling is complete, and 4) severe scarcity and prohibitive cost of Teflon beads in the size and quantity desired.

Automation

Further study needs to be done to create more reliable automatic control systems for the core drill. In particular, a good deal more work should be done on controls that are very sensitive to changes in the down hole situation, i.e., changes in lubricant pumping pressure, changes in vibration of the drill, and changes in the rate of penetration.

APPENDIX

CALCULATIONS/ COMPUTER USAGE



$$\sum F_x = R_x + 7270\cos\psi + R_{cyl}\cos\theta - 11273\text{ lbs} = 0$$

$$\sum F_y = R_y - 7270\sin\psi - R_{cyl}\sin\theta + 9290 = 0$$

$$(+)\ \sum M_o = 7270(\cos\psi')\,3.25 + R_{cyl}(\sin\theta)\,7 - 9290(8) = 0$$

$$\psi' + \psi = 67.4^\circ$$

$$8^\circ < \theta < 15 \quad ; \quad 0 < \psi < 6$$

$$61.4 < \psi' < 67.4$$

$$R_{cyl} = \frac{9290(8) - 7270(3.25)\cos\psi'}{7\sin\theta}$$

$$= \frac{9290(8) - 7270(3.25)\cos(61.4)}{7\sin 8^\circ}$$

$$= 64{,}700\text{ lbs.}$$

Use 2 cylinders, 1.5 safety factor

$$R_{cyls} = \frac{64{,}700(1.5)}{2} = 48{,}500\text{ lb. each.}$$

$$\frac{48{,}500\text{ lb.}}{2500\text{ lb/in}^2} = 19.4\text{ in}^2$$

$$\frac{\pi a^2}{4} = 19.4 \qquad a = 4.97$$

use (2) 5" cylinders with 40" stroke.

Pin Reactions

$$R_y = 7270 \sin 6° + 64700 \sin 15° - 9290$$
$$= 8215 \text{ lbs.}$$
$$R_x = 11273 - 7270 \cos 0° - 64700 \cos 8°$$
$$= -60{,}000 \text{ lbs.}$$

$$R_{max} = \sqrt{60{,}000^2 + 8215^2}$$
$$= 60{,}600 \text{ lbs.}$$

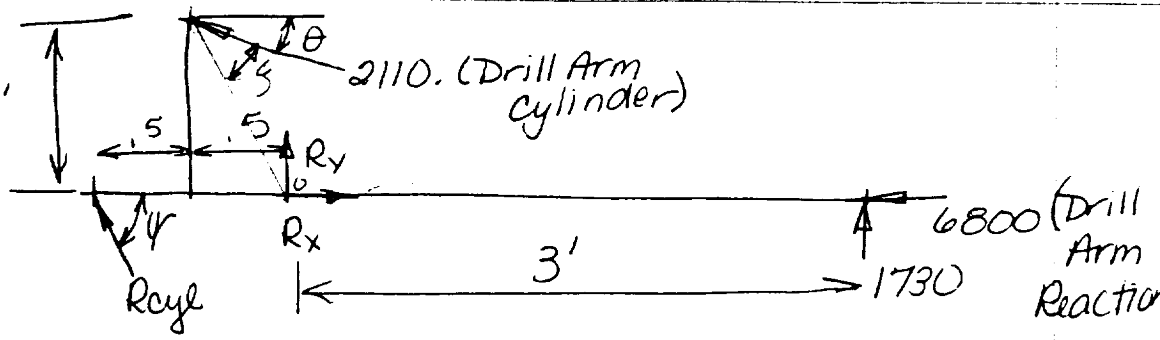
using a material with S_{sy} = 15,000 psi

$$A_s = \frac{60{,}600(1.5)}{15{,}000} = 6.06 \text{ in}^2$$

$$6.06 = \frac{\pi d^2}{4}$$

$$d = 2.77$$

use a 3" pin



$$\Sigma F_x = R_x - 6800 - 2110\cos\theta - R_{cyl}\cos\psi = 0$$

$$\Sigma F_y = R_y + R_{cyl}\sin\psi + 2110\sin\theta + 1730 = 0$$

$$\circlearrowleft \Sigma M_0 = -1730(3ft) - 2110(1.11ft)\sin\xi + R_{cyl}(1)\sin\psi = 0$$

Our range of motion

$$\theta + \xi = 60°$$

$$71° < \psi < 76° ; \quad 3° < \theta < 14°$$

at $\theta = 3°$; $\xi = 57°$

$\psi = 76°$

$$-1730(3) - 2110(1.11)\sin 57° + R_{cyl}\sin 76° = 0$$

$$R_{cyl} = 2426 \text{ lbs}$$

at $\theta = 14°$ $\xi = 46°$

$\psi = 71°$

$$-1730(3) - 2110(1.11)\sin 46° + R_{cyl}\sin 71° = 0$$

$$R_{cyl} = 7270 \text{ lbs max.}$$

Sizing Cylinder

$$\frac{7270 \text{ lbs}}{2500 \text{ psi}} = 2.90 in^2 \times 1.5 \text{ safety factor} = 4.36 in^2$$

$$\frac{\pi d^2}{4} = 4.36 in^2 \qquad \text{stroke} =$$

$$d^2 = 5.55 in$$

$$d = 2.35 \quad \text{use (1) 3" bore cylinder}$$

2^{nd} Arm Calculations.

$$R_x = 6800 + 2110\cos 3^\circ + 7270\cos 71^\circ$$

$$R_x = 11273 \text{ lbs.}$$

$$-R_y = 7270\sin 76^\circ + 2110\sin 14^\circ + 1730$$

$$-R_y = 9290 \text{ lbs.}$$

$$R_{max} = \sqrt{11273^2 + 9290^2} = 14{,}610 \text{ lbs.}$$

Sizing Pin at joint

$$\tau = \frac{F}{A}$$

$$S_{sy} = \tau = 15.0 \text{ kpsi}$$

$$F = 14{,}610 \text{ lbs}$$

$$A = \frac{14{,}610}{15{,}000} = .975 \times 1.5 \text{ fact. safety} = 1.46 \text{ in}^2$$

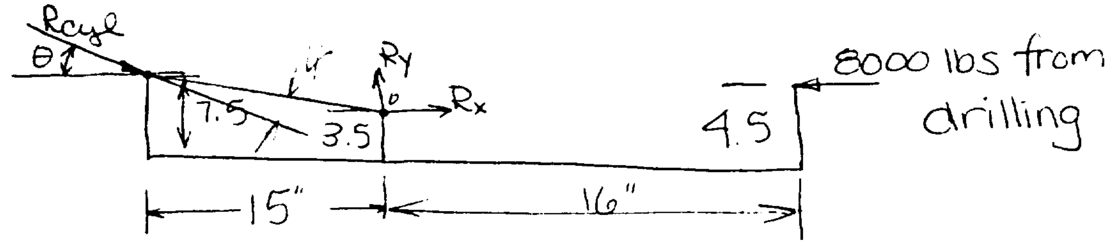
$$\frac{\pi d^2}{4} = 1.46$$

$$d^2 = 1.86$$

$$d = 1.36 \text{ in}$$

$$\boxed{\text{use } d = 1.375 \text{ in}}$$

CALCULATIONS: DRILL ARM (3rd Arm)



$$\overset{+}{\rightarrow} \sum F_x = R_{cyl} \cos\theta + R_x - 8000 = 0$$

$$\overset{+}{\uparrow} \sum F_y = -R_{cyl} \sin\theta + R_y = 0$$

$$\circlearrowleft \sum M_o = -R_{cyl} \sin\psi (15.1) - 8000 (\text{in}) = 0$$

From the kinematics

$\psi = \theta - 7.6^\circ$ $\qquad -14.6 < \psi < 61.6^\circ$

$-7^\circ < \theta < -55^\circ$

$$R_{cyl} = -\frac{8000}{15.1 \sin\psi} = \left\{ \begin{array}{l} 2110.\ \text{lbs.} - \text{max} \\ \text{req'mt. for cylinder} \end{array} \right\}$$

In this position:

$R_y = 2110 \sin(-55^\circ) = -1730$ lbs.

$R_x = 8000 - 2110 \cos(-55^\circ) = 6800$ lbs

$R_{total} = \sqrt{1730^2 + 6800^2} = 7006$ lbs. pin reaction

Maximum shear on pin =

$$\sqrt{R_{y\,max}^2 + R_{x\,max}^2} = \sqrt{2110^2 + 8000^2} = 8270 \text{ lbs}$$

Using steel with $S_y = 26$ kpsi

$S_{sy} = .577 S_y = 15.0$ kpsi

$$A_{shear} = \frac{F}{S_{sy}} = \frac{8270}{15{,}000} = .55 \text{ in}^2$$

(3a)
DRILL ARM CALCULATIONS (con't)

$A_{shear} = .55 in^2$

$n = 1.5$

$A_s = .827 in^2 = \frac{\pi d^2}{4}$

$d^2 = 1.05$

$d = 1.026 in$

use $d = 1.125 in$ for pin joint

Sizing cylinder

we know stroke length = 19"

$F_{cyl} = 2110 lbs$

pressure = 2500 psi

$n = 1.5$

area of cylinder bore $= \frac{3165 lbs}{2500 psi} = 1.26 in^2$

$\frac{\pi d^2}{4} = 1.26 in^2$

$d^2 = 1.61 in$

$d = 1.26 in$

1" bore will not work

∴ use a 2" bore; 20" stroke

SWING PIVOT FRAME CALCULATIONS

SUPPORT PLATE:

(Buckling) $P_{CR} = Pn$, $P = 60{,}000$ lbf , $n = 3$

$P_{CR} = 180{,}000$

$$I = \frac{P_{CR}\,l^2}{C\pi^2 E}$$

$l = 14$ in , $E = 30\times10^6$ psi

$C = 1.2$ (For one end fixed, one free)

$= .0994\ \text{in}^4$

$I = \frac{bh^3}{12}$; $b = 10$ $\Rightarrow$ $h = \left[\frac{12I}{10}\right]^{1/3}$

SUBSTITUTING YIELDS

$h = .492$ in

$\frac{l}{k} = \frac{14}{.289\,(.492)} = 98$; $\left(\frac{l}{k}\right)_1 = \sqrt{\frac{2\pi^2 CE}{S_y}}$ $S_y = 84\times10^3$

$\left(\frac{l}{k}\right)_1 = 92$

Therefore this is an Euler Column and this criterion is valid.

(Deflection)

$P = Fn$; $F = 40{,}500$ lbf $\therefore$ $P = 122{,}000$ lbf

$$y_{14} = \frac{122{,}000\ 14^2\ [14 - 3(14)]}{6EI}$$

For 2 in. thickness

$I = 6.67\ \text{in}^4$

$y = .56$ in

This will serve as a first approximation when supports are added deflection will be checked.

RING RETAINING BOLTS :

Shear load = 122,000 lbf   A = Cross-sectional Area of bolts

$$\tau = F/A = \frac{122{,}000}{6 \times \frac{\pi(.75)^2}{4}} = 46{,}025\,psi$$

maximum allowable shearstress $\tau = .5\,S_y$

Therefore use SAE grade 8 CAPSCREWS (.75" dia)

$S_y = 130 \times 10^3\,psi$

$\tau = 65 \times 10^3\,psi$

OUTRIGGER ARMS

$$P_{cr} = \frac{122000}{2} = 61{,}000\,lbf$$

$$I = \frac{61{,}000\,l^2}{CE\pi^2}$$

l = length of arms = 70"

$C = 1$ (both rounded)

$I = .993\,in^4$

$$I = \frac{bh^3}{12} \qquad b = 3\,in.$$

$$h = \left[\frac{12I}{3}\right]^{1/3} = 1.6\,in$$

$$\left(\frac{l}{k}\right) = \frac{70}{.289(1.6)} = 151$$

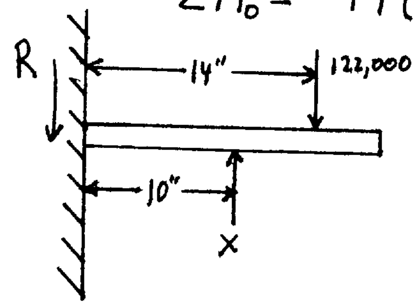
From previous calculations

$$\left(\frac{l}{k}\right)_1 = 92 \qquad \text{Therefore Euler criterion holds.}$$

SUPPORT SIZING:

$$\Sigma F = 122{,}000 - R_o - X_o = 0$$

$$\Sigma M_o = -14(122{,}000) + 2.$$



$X = 726{,}808$

$R = -604{,}808$

There are 2 parallel supports therefore each handles 1/2 the total load.

$P_{cr} = 363{,}000$

$$I = \frac{P_{cr}\,\ell^2}{C\,\pi^2 E}$$

ℓ = length of column through centroid of actual support

$= .0056$

b = width of column

$$I = \frac{bh^3}{12} = \frac{4}{12}h^3$$

$$h = \left[\frac{12}{4} I\right]^{1/3} = .25 \text{ in}$$

Therefore .25in sheet steel is used for support.

POST PIN

Bearing stress in post pin:

$$\sigma = \frac{F}{A}$$

$A = td$ where t = thickness of bearingplate
d = diameter of pin.

$t = 3.5$ in

$d = 6$ in

$F = 180{,}000$ lbf

$$\sigma = \frac{180{,}000}{21} = 8571 \text{psi}$$

MAXIMUM allowable shear stress

$$\tau = \tfrac{1}{2} S_y = \tfrac{1}{2}\, 84 \times 10^3 \text{psi}$$

$$= 42{,}000 \text{psi}$$

LUBRICATION & COOLING

TEFLON CHARACTERISTICS

$S_{COMP} = 1700$ psi
$S_{ut} = 4500$ psi
$H_{ROCK.} = 28$ (R-SCALE)
POISSON'S RATIO $\equiv \eta = 0.46$ @ 73°F
SPECIFIC GRAVITY = 2.2
WATER ABSORBTION = 0.005 %
THERMAL CONDUCTIVITY $\equiv k = 1.5 \; \frac{B}{hr\; ft^2\; °F}$
MAXIMUM TEMPERATURE = 500°F
DENSITY $\equiv \rho = 134.16 \; lb/ft^3$
NON-FLAMMABLE

CALCULATIONS

EARTH CONDITIONS FOR DRILLING
- PENETRATION RATE 4 IN/MIN
- WATER FLOW RATE $9 \leftrightarrow 12$ gal/MIN
  $1.2 \leftrightarrow 1.6$ ft³/MIN

DUE TO HIGHER THERMAL CONDUCTIVITY AND HIGHER OPERATING TEMPERATURES, SIMILAR FLOW RATE CAN BE ASSUMED

$$\text{FLOW RATE} \approx 10\ gal/MIN = 1.34\ ft^3/MIN = 0.022\ ft^3/sec$$

IN A 1½" PIPE

$$\text{AREA} = 1.77\ IN^2 = 0.0123\ ft^2$$

$$\therefore \text{VELOCITY} \equiv V = 0.022 \frac{ft^3}{sec} \times \frac{1}{0.0123\ ft^2} = 1.79 \frac{ft}{SEC}$$

$$\dot{m} = \rho V A = \left(134.16 \frac{lb}{ft^3}\right)\left(1.79 \frac{ft}{sec}\right)\left(0.0123\ ft^2\right)$$

$$= 2.95\ lb/sec$$

LUBRICATION & COOLING (CONT.)

HEAD LOSS IN PIPE

$$h_L = 2 f_f \frac{L}{D} \frac{V^2}{g}$$

$L = 100$ ft

$D = 0.25$ ft

$V = 1.79$ ft/sec

$g = \frac{32.2}{6} = 5.33$ ft/sec²

$f_f = 0.006$

$$h_L = 2(0.006) \cdot \frac{100}{0.25} \cdot \frac{(1.79)^2}{5.33} = 2.89 \text{ ft}$$

PRESSURE DIFFERENCE $\equiv \Delta P \approx 55$ psi

∴ LOOKING IN ROPER PROGRESSING CAVITY CATALOG, THE PUMP BEST SUITED FOR OUR PURPOSE IS STK # 71202 WITH THE FOLLOWING CHARACTERISTICS:

	Gal/rev	PUMP SPEED DIFF. PRESS. psi	300 RPM GPM	300 RPM MIN. HP	600 RPM GPM	600 RPM MIN. HP	900 RPM GPM	900 RPM MIN. HP
		0	5.8	1/2	12.0	1/2	18	3/4
71202	2.02	40	4.0	1/2	9.5	1/2	16	1
		75			5.5	3/4	12	1 1/2

Computer Usage

Computer usage was very minimal in our design. The area in which it could have helped us the most was in the design of the arm. The use of a CADD system would have cut design time and allowed for a more meaningful optimization process. HP-41CV's were used in determining weld sizes and doing stress analysis on some members.

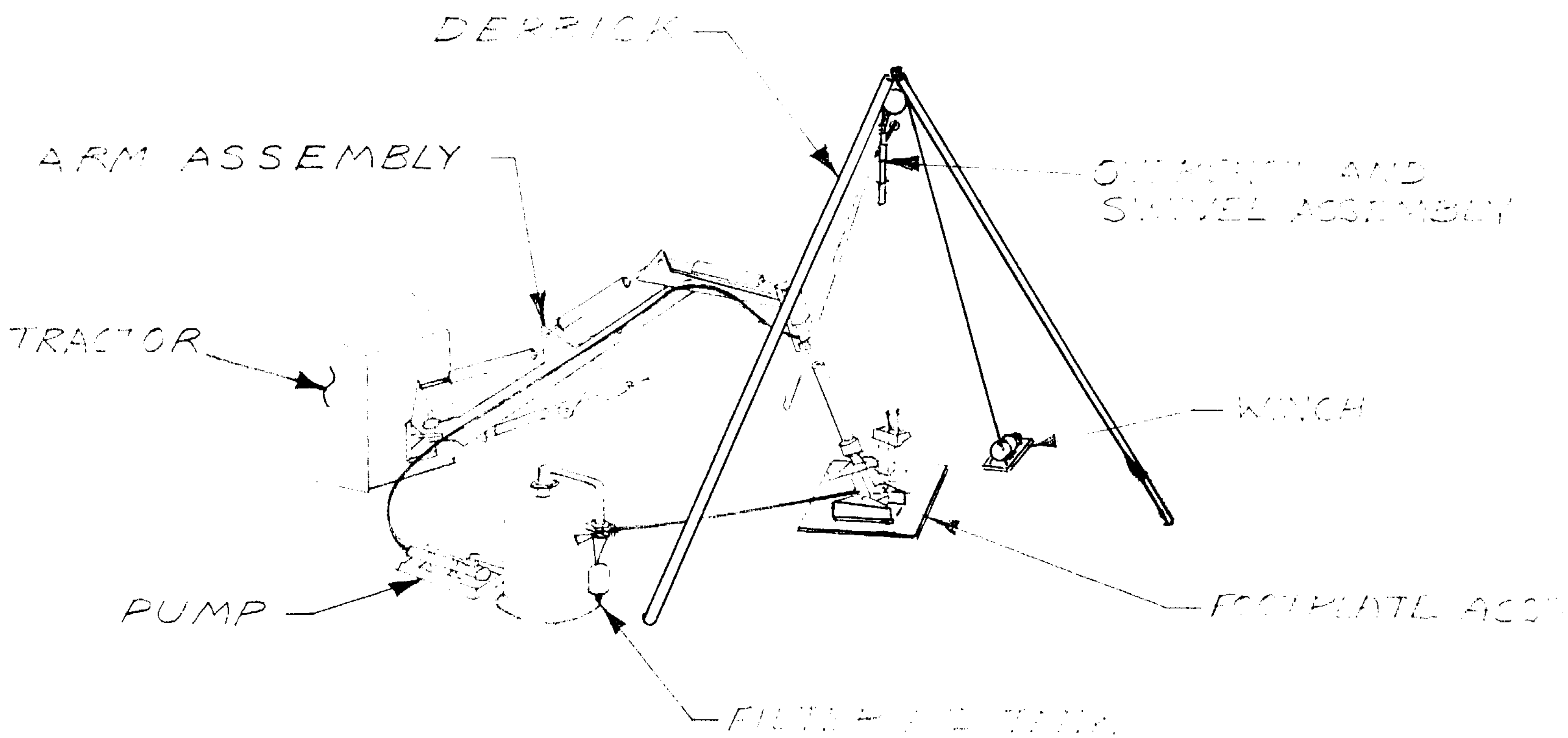
DRAWINGS

PARTS LIST

ITEM	DRAWING NUMBER	DESCRIPTION	MFGR	PART #	WEIGHT LBF	QUANTITY
-	-	ARM ASSEMBLY	-	-	-	-
1	101	TRACTOR MOUNTING PLATE	-	-	570	1
2	102	POST PIN	-	-	250	1
3	103	PIN CAP	-	-	10	1
4	104	OUTRIGGER ASSY	-	-	213	2
5	105	SWING PLATE	-	-	50	2
6	106	GRIPPER	-	-	10	1
7	107	BOOM ARM	-	-	850	1
8	108	MIDDLE ARM	-	-	360	1
9	109	DRILL ARM	-	-	110	1
10	110	AUX ARM #1	-	-	60	1
11	111	AUX ARM #2	-	-	72	1
12	112	SWING PIN	-	-	8	1
13	113	SWING PIN	-	-	8	1
14	114	SWING PIN	-	-	7	1
15	115	SWING PIN	-	-	7	1
16	116	SWING PIN	-	-	7	1
17	117	5" BORE X 40" STROKE	ENERGY	CRT-500	200	2
18	118	3" BORE X 40" STROKE	ENERGY	CRT-300	100	1
19	119	2" BORE X 20" STROKE	ENERGY	CRT-200	65	1
20	120	2" BORE X 12" STROKE	ENERGY	CRT-200	50	1
21	121	2" BORE X 10" STROKE	ENERGY	CRT-200	43	2
-	200	DRILLING ASSY	-	-	-	-
1	-	PRETORQUE & BREAKOUT TOOL	LONGYEAR	41600	750	1
2	201	FOOT PLATE	-	-	232	1
3	-	SIDE FEED DISCHARGE SWIVE	ACKER	21060-5	30	1
4	202	SWIVEL ATTACHMENT	-	-	1	2
5	-	NQ DRILL CASING 2'	LONGYEAR	26368	17.4	1
6	-	NQ DRILL RODS 5'	LONGYEAR	24916	26	20
7	-	PUMP-IN TYPE A WL CORE	ACKER	10058-1	98	1
8	-	REAMING SHELL	LONGYEAR	6NQPUG/	7	1
9	-	SERIES 6 RED IMPREG BIT	LONGYEAR	1NQHUF/	11	1
10	-	BQ TO NQ SUB	LONGYEAR	25730	5	1
11	-	HYDRACORE 28 DRILL HEAD	LONGYEAR	-	218	1
-	-	1/2-20UNF BOLT 1.25 LONG	-	-	-	10
-	-	1/2-20UNF NUTS	-	-	-	6
-	-	1/4-28UNF 1.0 LONG BOLTS	-	-	-	4
-	300	CORE RETRIEVAL ASSY	-	-	-	
1	-	PUMP IN OVERSHOT	ACKER	10123	22	1
2	-	SIDE FEED H2O SWIVEL	ACKER	21060-4	18	1
3	-	WIRELINE STUFFING BOX	MATHEY	STUFF B	12	1
4	-	ALUM. TRIPOD DERRICK	ACKER	25505-2	90	100'
5	-	3/16" HOIST CABLE	ACKER	21035-6	62	1
6	-	PLANETARY HYDR. WICH	PULL MAST	PL2-12-	174	
	400	LUBRICATION SYSTEM ASSY	-	-	-	-
1	401	PROGRESSING CAVITY PUMP	ROPER	71202	210	1
2	402	TANK/PUMP CONNECTING PIPE	-	-	162	1
3	403	FILTER CONE/TANK PIPE	-	13	1	
4	-	4" FILTER CONE ASSY	COOPER	2570-22	50	1
5	-	SILT POT ASSY	COOPER	6892	50	1

PARTS LIST

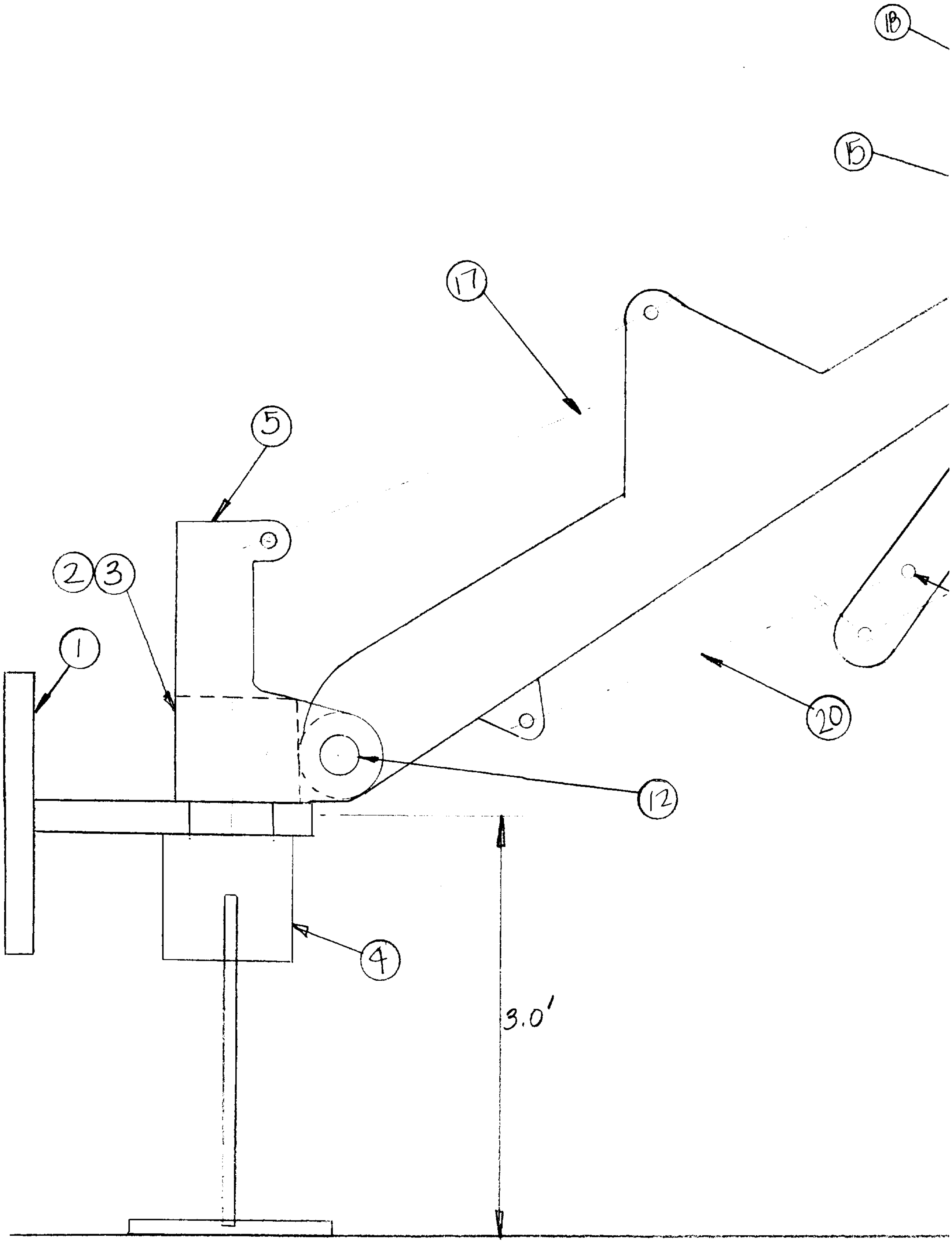
ITEM	DRAWING NUMBER	DESCRIPTION	MFGR	PART #	WEIGHT LBF	QUANTITY
6	-	1.25 NPT H20 SWIVEL HOSE	LONGYEAR	18912	18	3
-	-	WATER SWIVEL COUPLING	LONGYEAR	18910	3.5	1
-	-	3/4-16UNF BOLTS	-	-	-	8
-	-	3/4-16UNF NUTS	-	-	-	8
-	-	5/8-16UNF BOLT	-	-	-	8
-	-	5/8-16UNF NUTS	-	-	-	8
-	-	TRIFLON MICRO-BEADS	CLIFTON	-	1790	LOTS
-	500	CONTROL SYSTEM DIAGRAM	-	-	-	-
-	501	ARM #1 HYDRAULIC CIRCUIT	-	-	-	-
-	502	ARM #2 HYDRAULIC CIRCUIT	-	-	-	-
-	503	DRILLING CONTROLS	-	-	-	-
				-	7107.9	



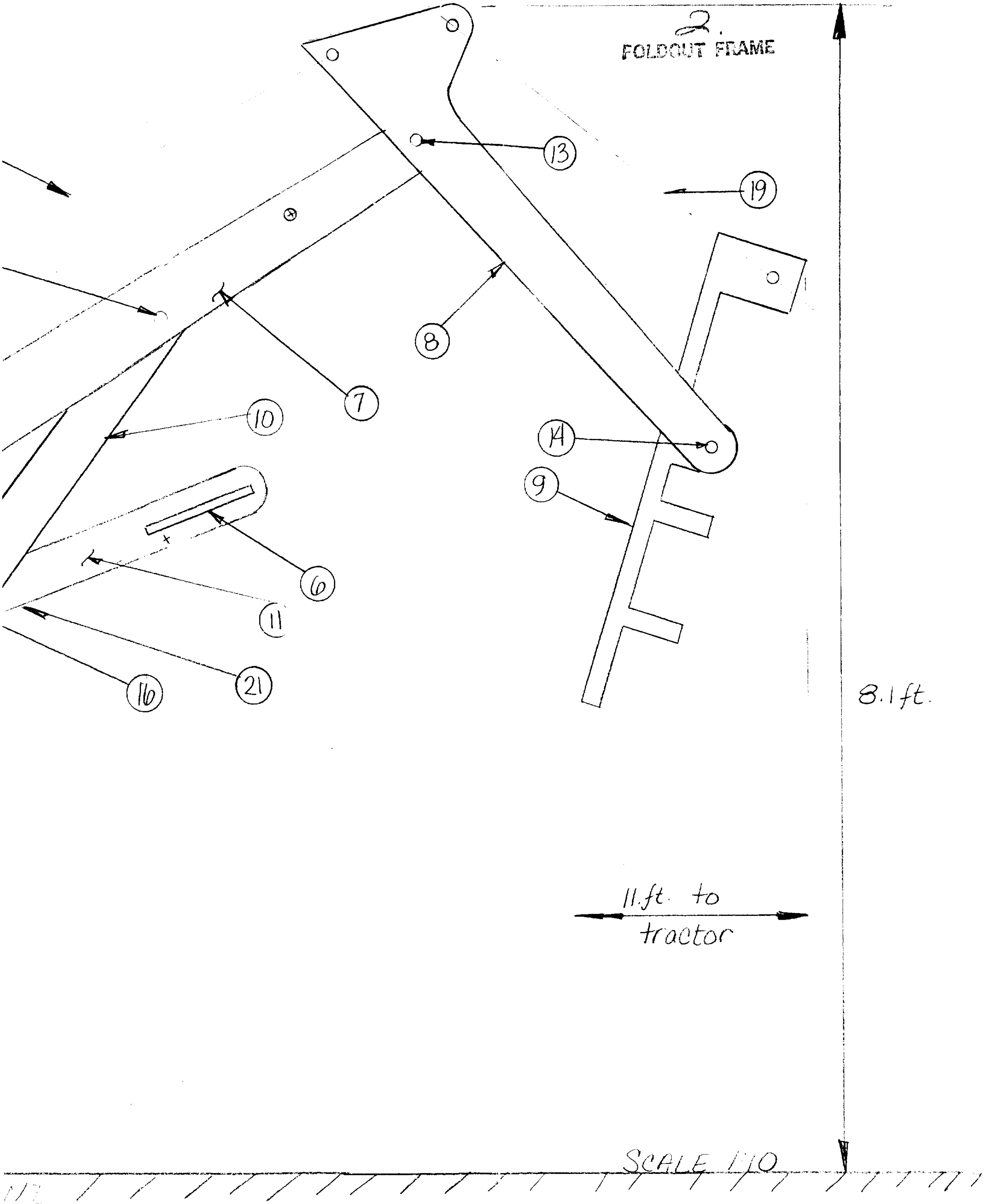
SITE ASSEMBLY
DWG NO. 001

/.

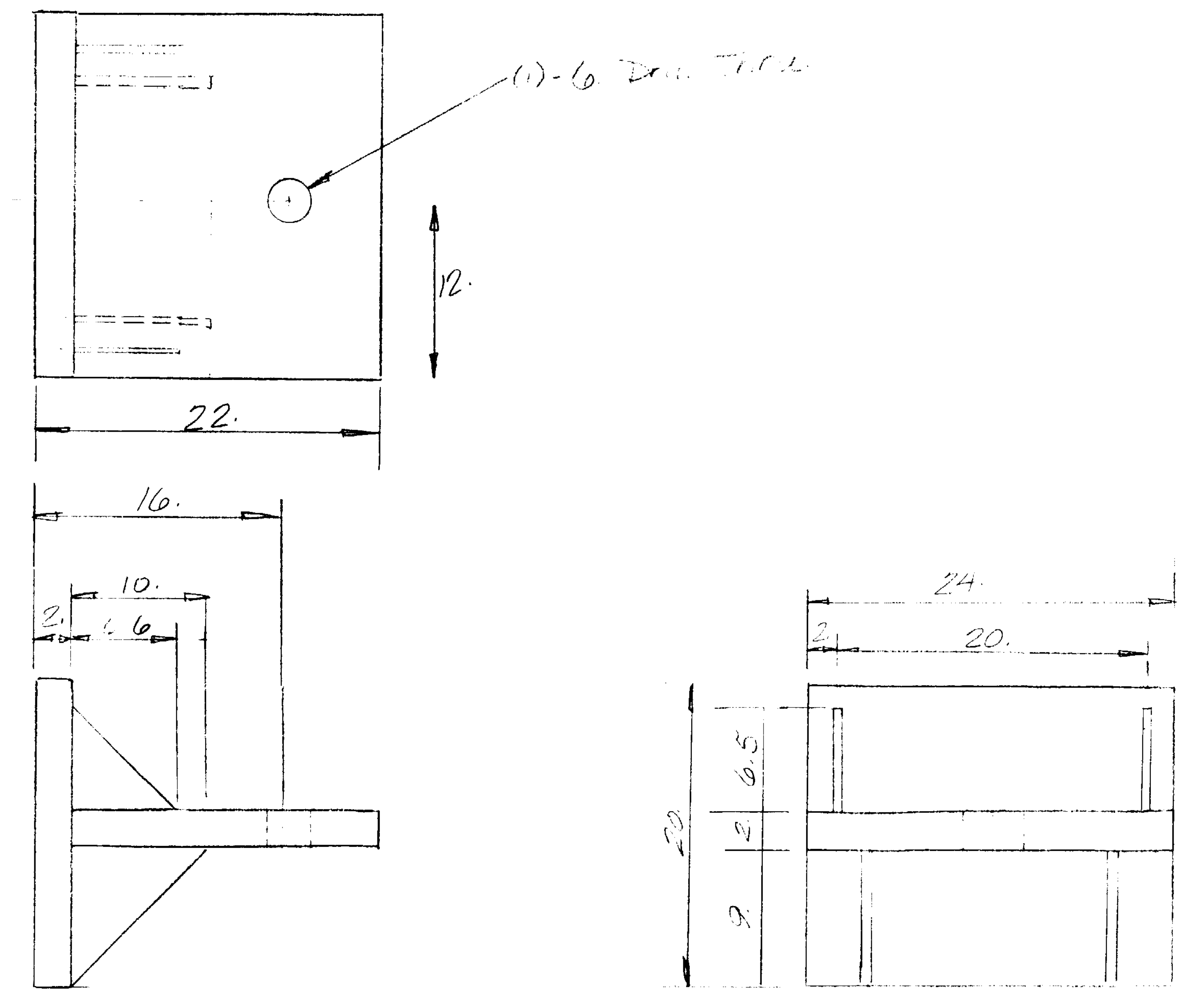
FOLDOUT FRAME



2.
FOLDOUT FRAME



ARM [illegible] POSITION
DRG 100

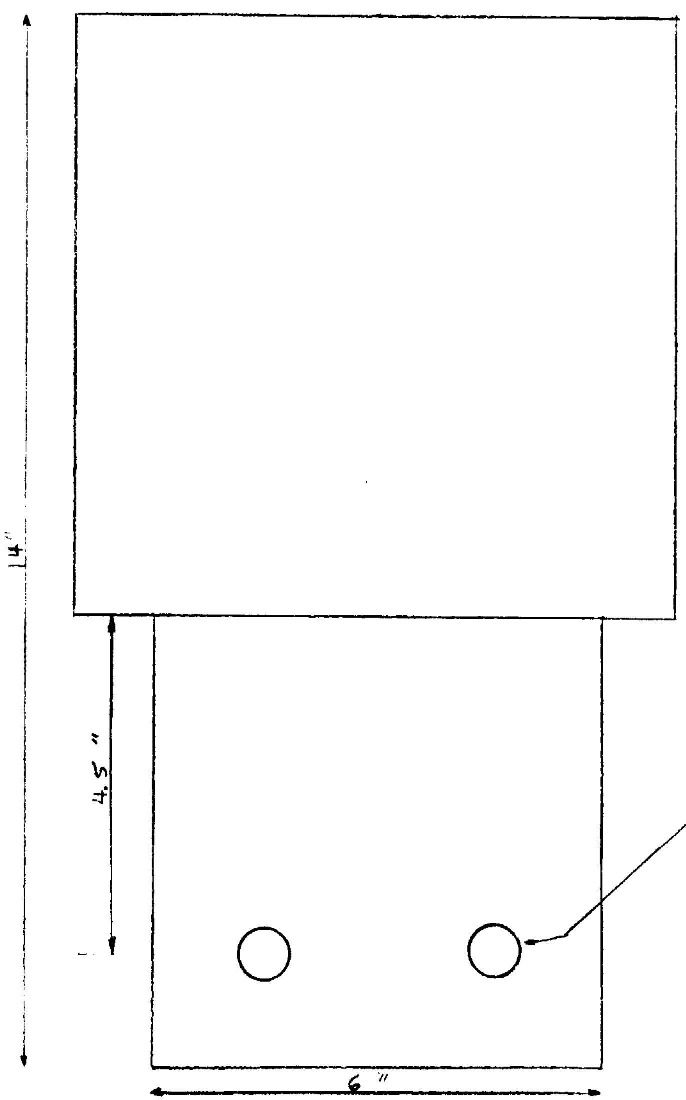


EST. WT. = 570 lbs
MATL 1035 STEEL

101- TRACTOR MOUNTING PLATE

102 – POST PIN

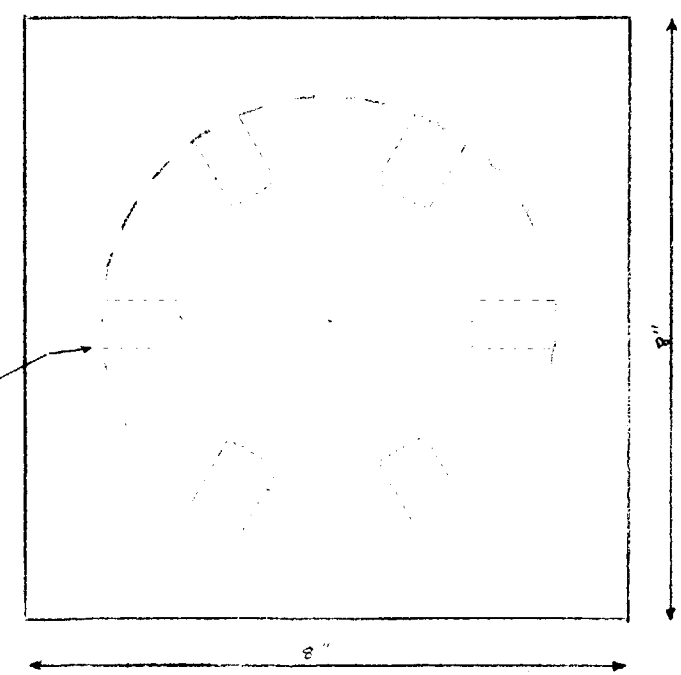
EST. WT. : 250 lbs.
MAT. : 1035 STEEL



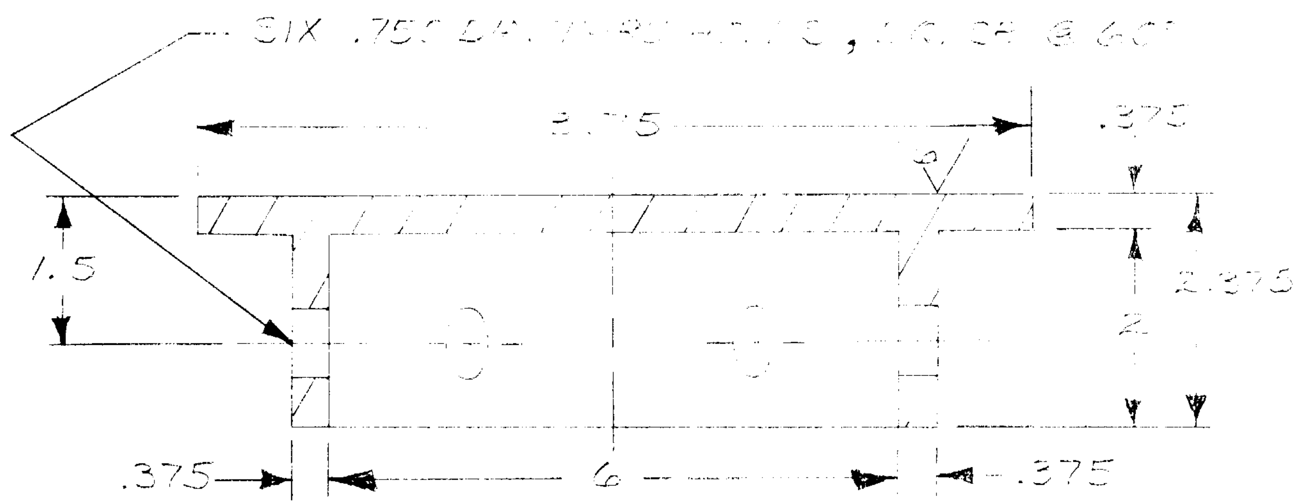
SIDE VIEW

3/4" STANDARD THREADS (TAPPED) 1" DEEP

6 HOLES SPACED 60° APART

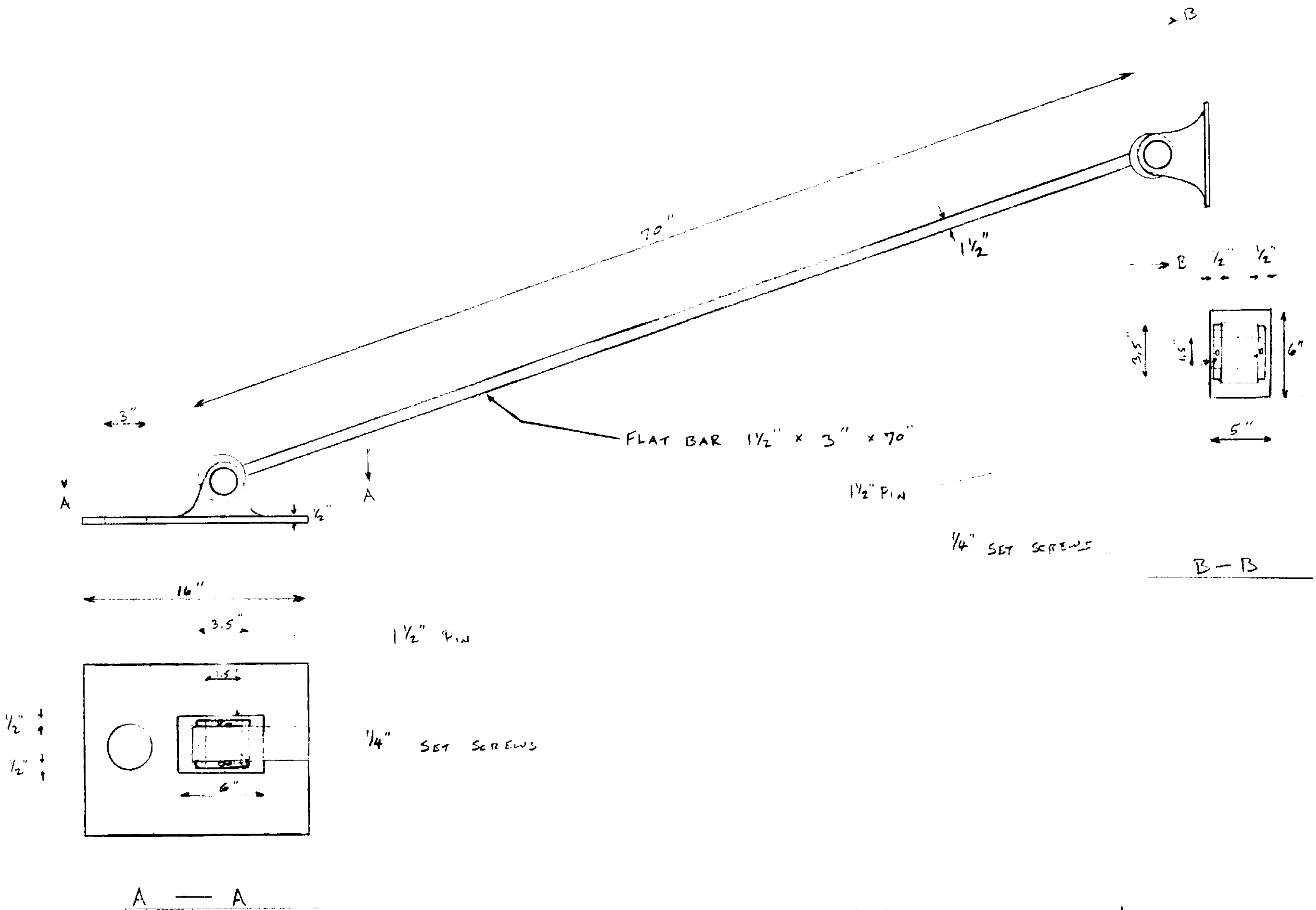


TOP VIEW



PIN CAP

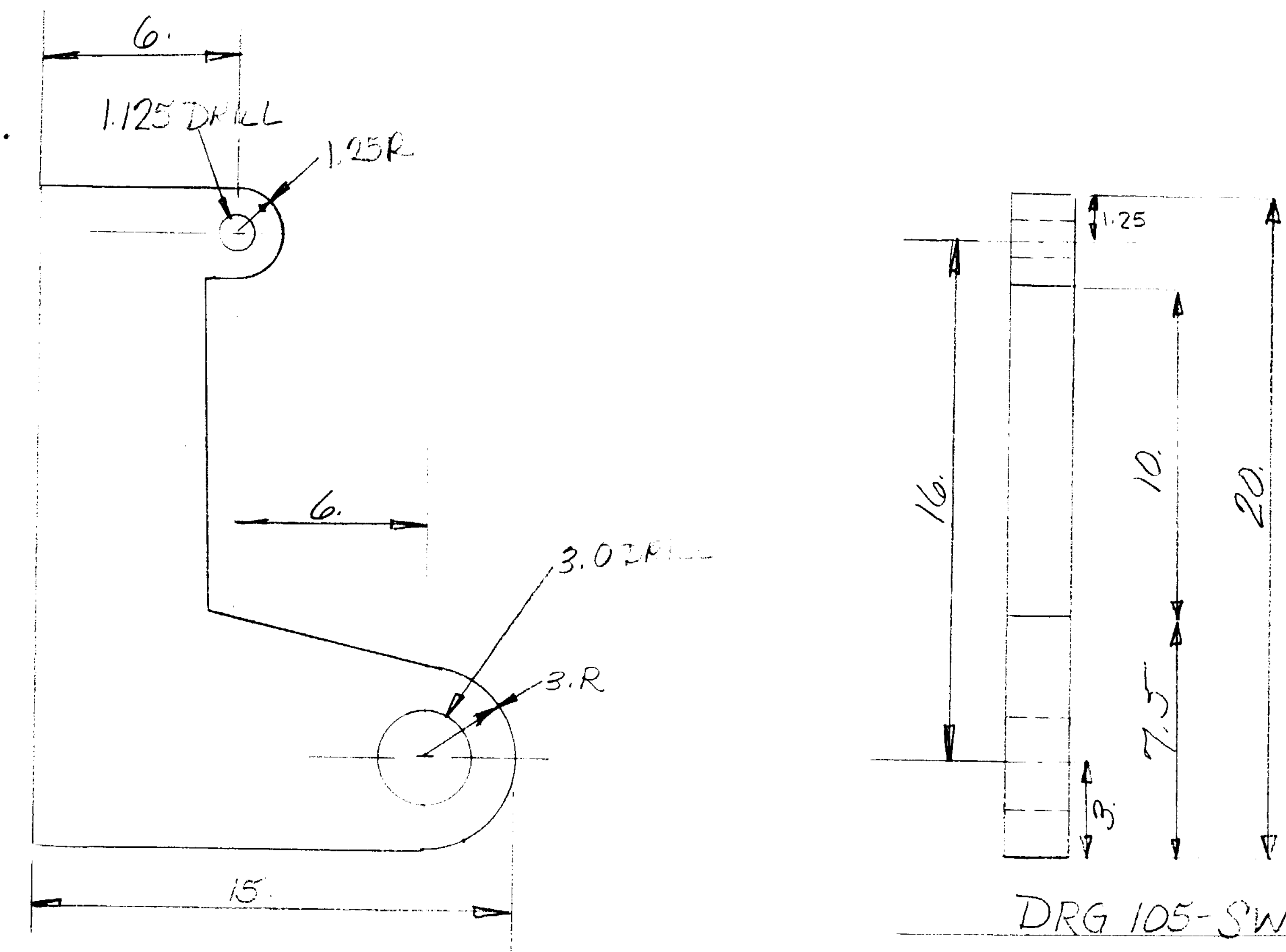
DWG NO. [illegible]
1035 STEEL



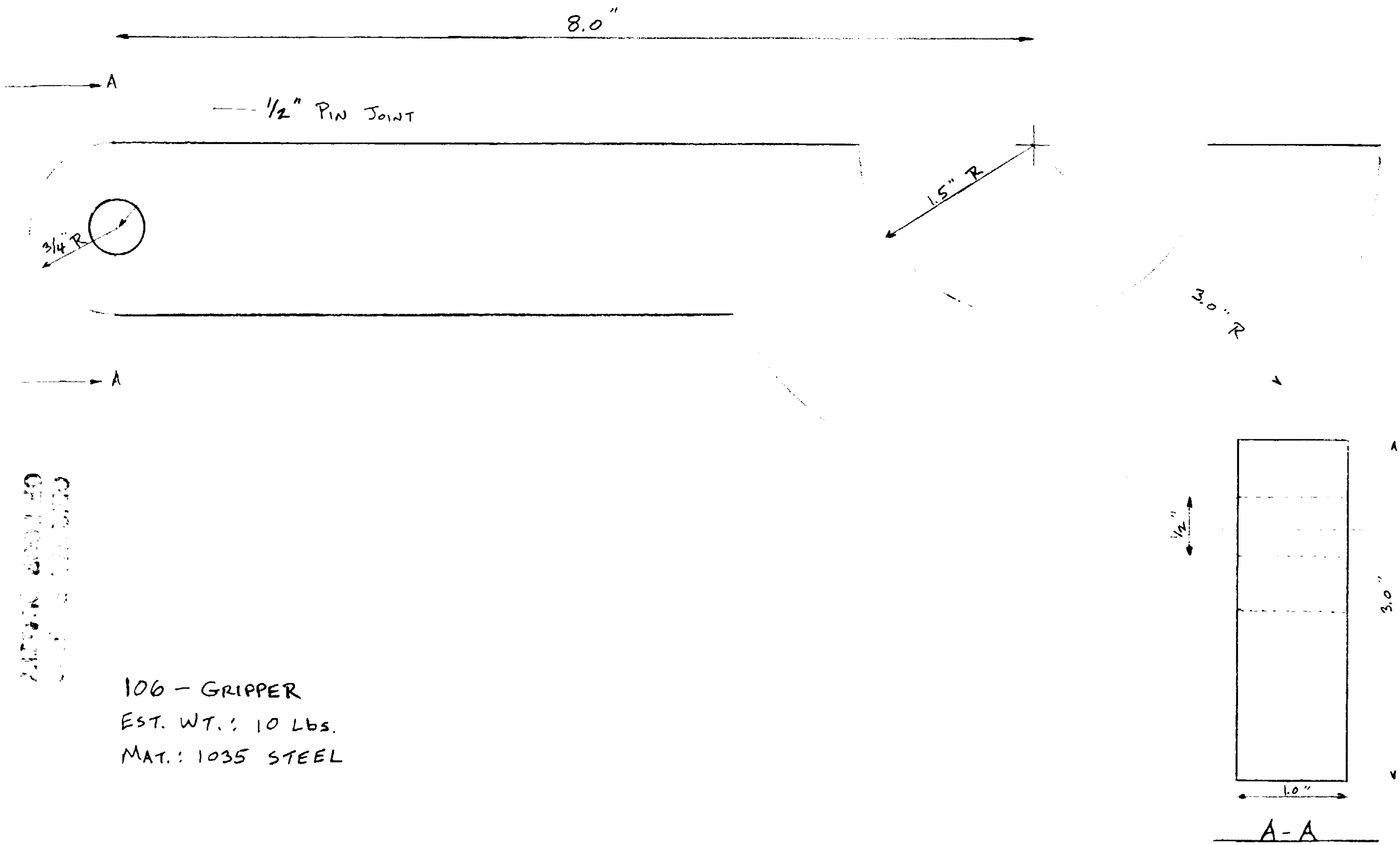
104 - OUTRIGGER ASSY.

EST. WT. PER ARM (2 EACH): 70 LBS.

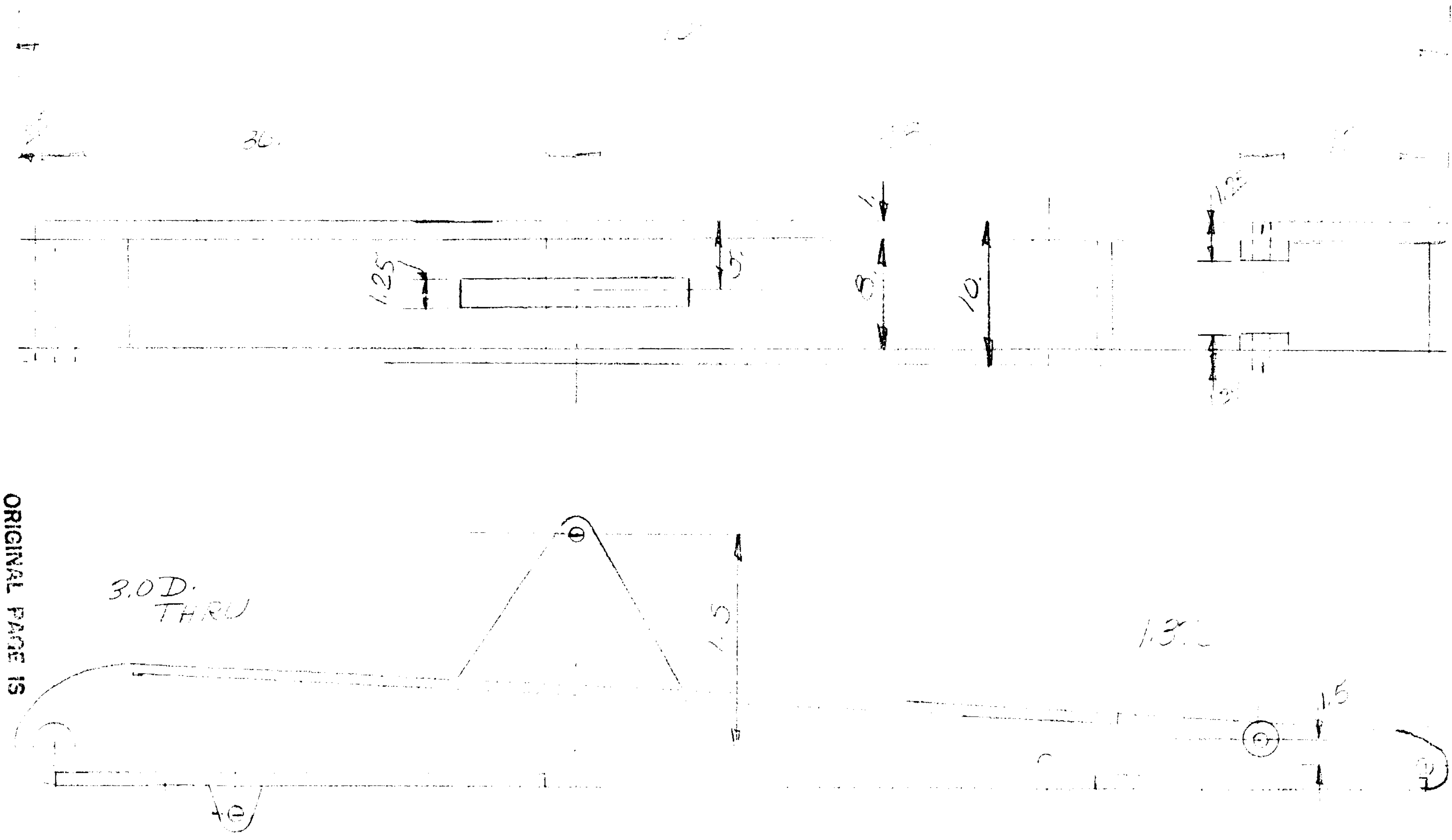
MAT.: 1035 STEEL



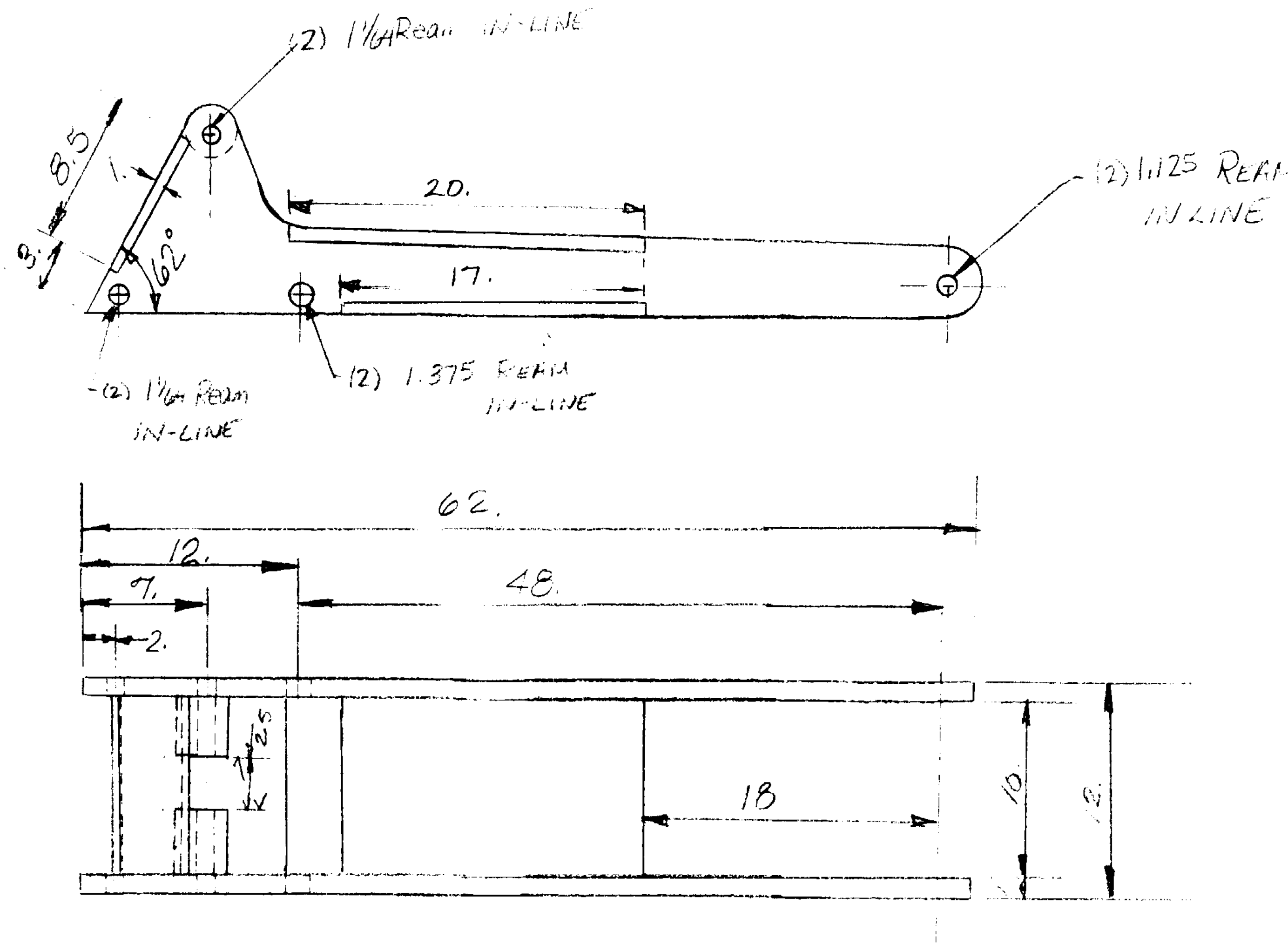
DRG 105- SWING PLATE



106 – GRIPPER
EST. WT.: 10 Lbs.
MAT.: 1035 STEEL



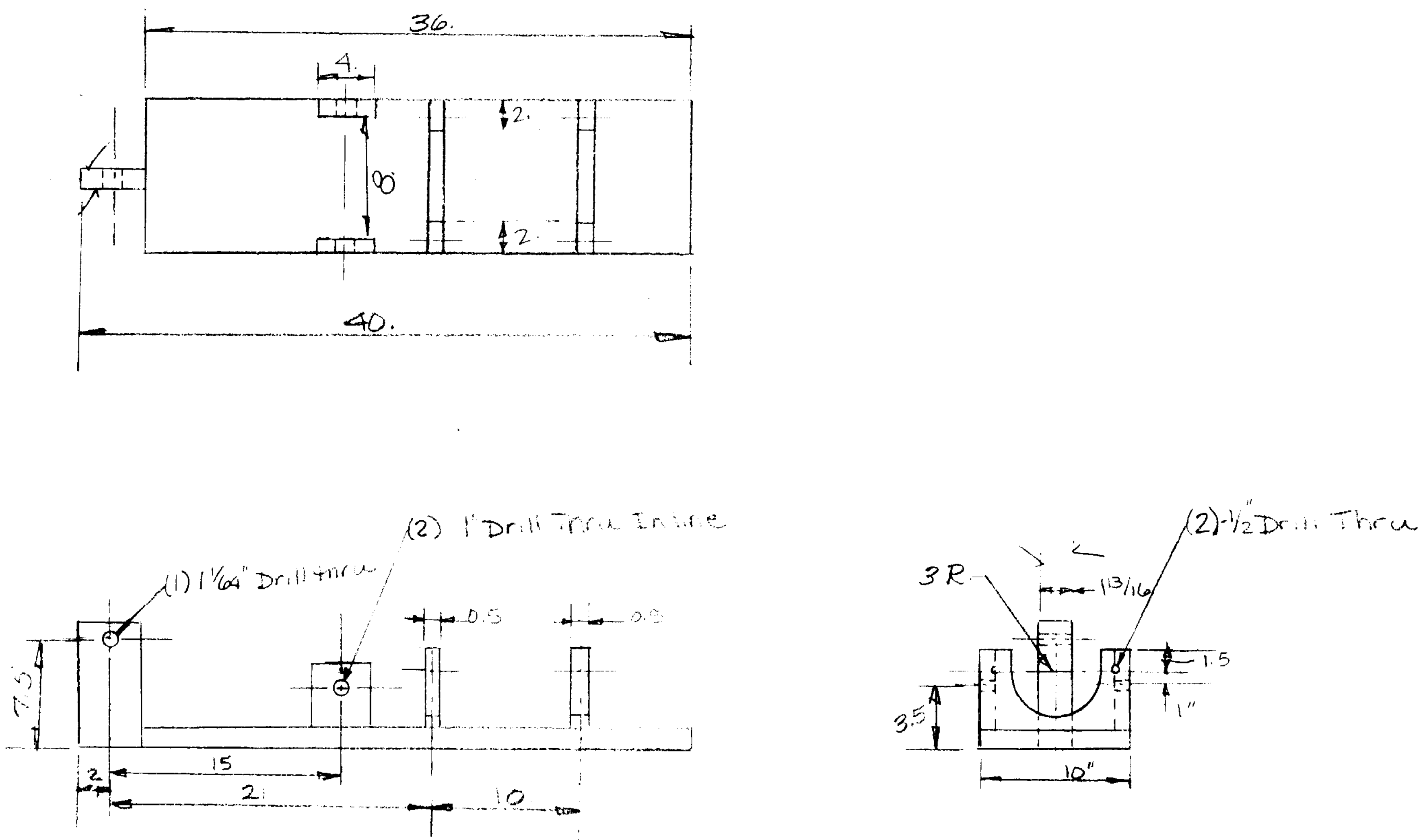
107- BOOM



108 - MIDDLE ARM

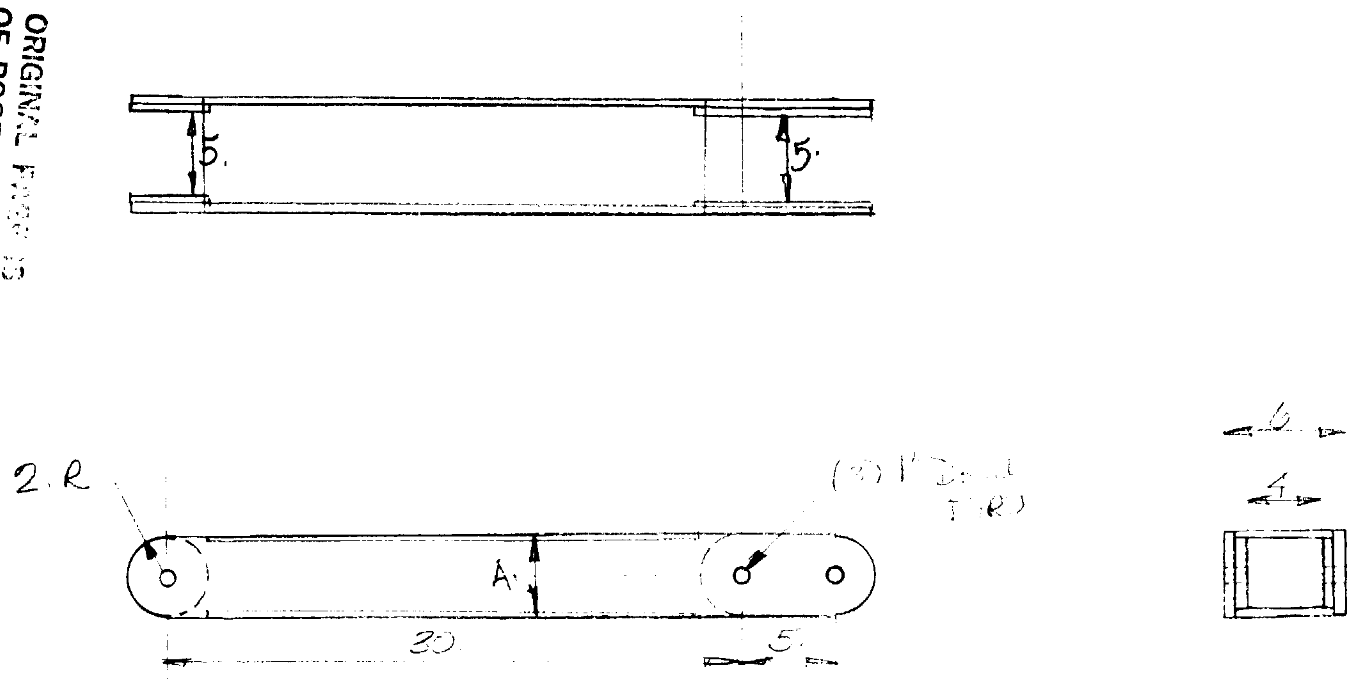
SCALE 1:10

DRAWN BY: NJC



109 - DRILL ARM · SCALE 1:10

DRAWN BY: NJS


5.
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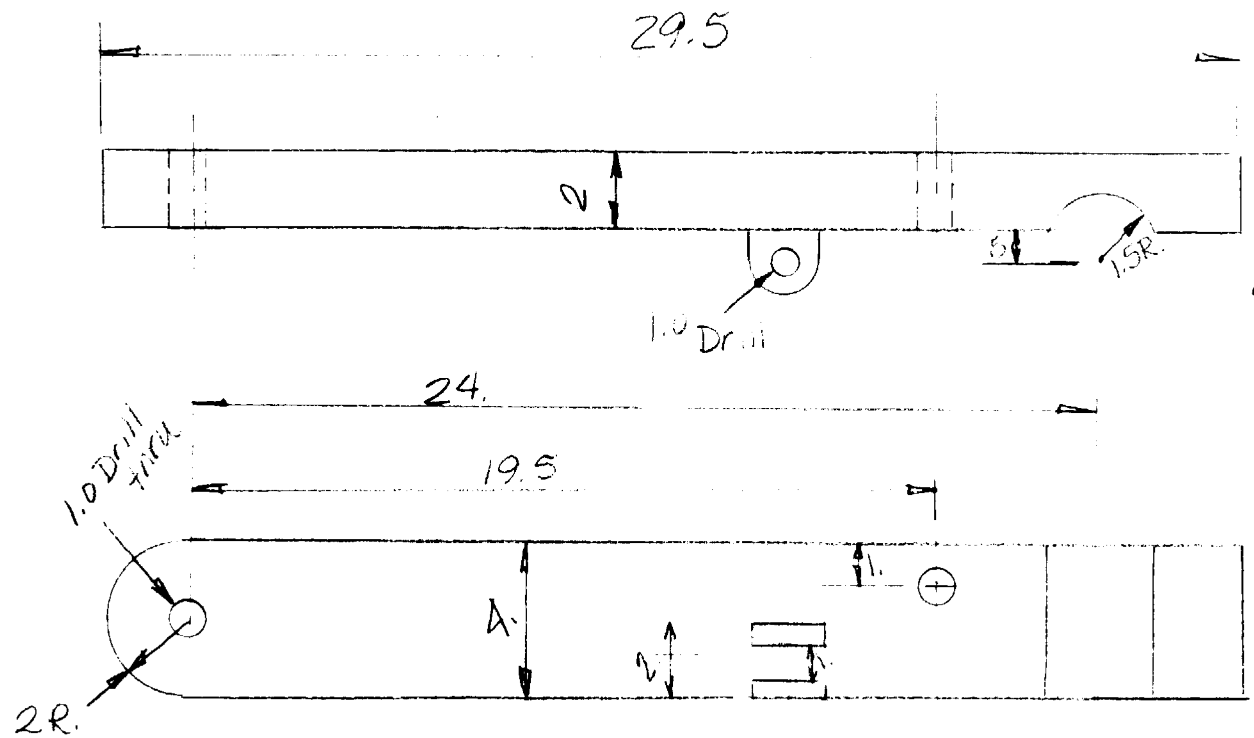
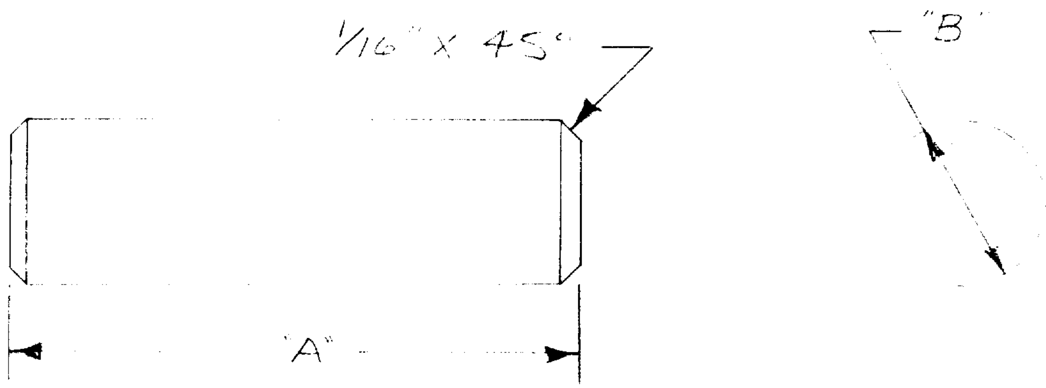


EST WT ≡ 72 lbs.

DRG # [illegible] ARM F2

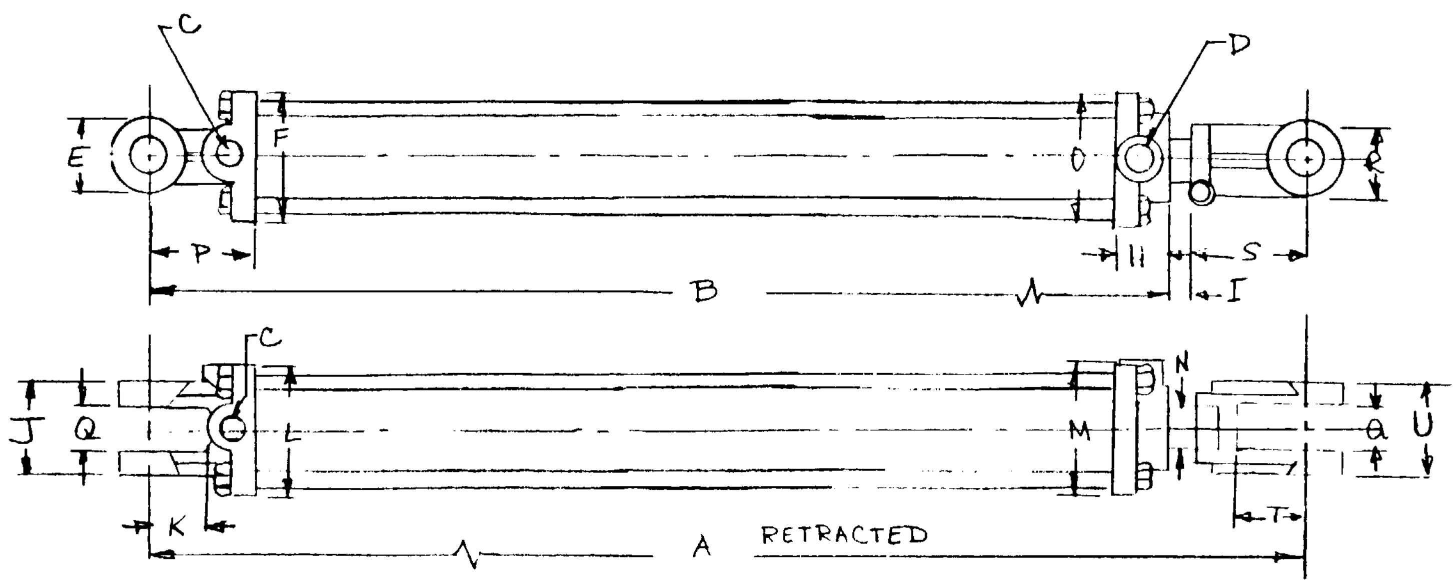
PIN No.	"A"	"B"
112	11.0	3.0
113	13.0	1.375
114	13.0	1.5
115	11.0	1.0
116	7.0	1.0



SWING PINS

1035 STEEL

DWG 112

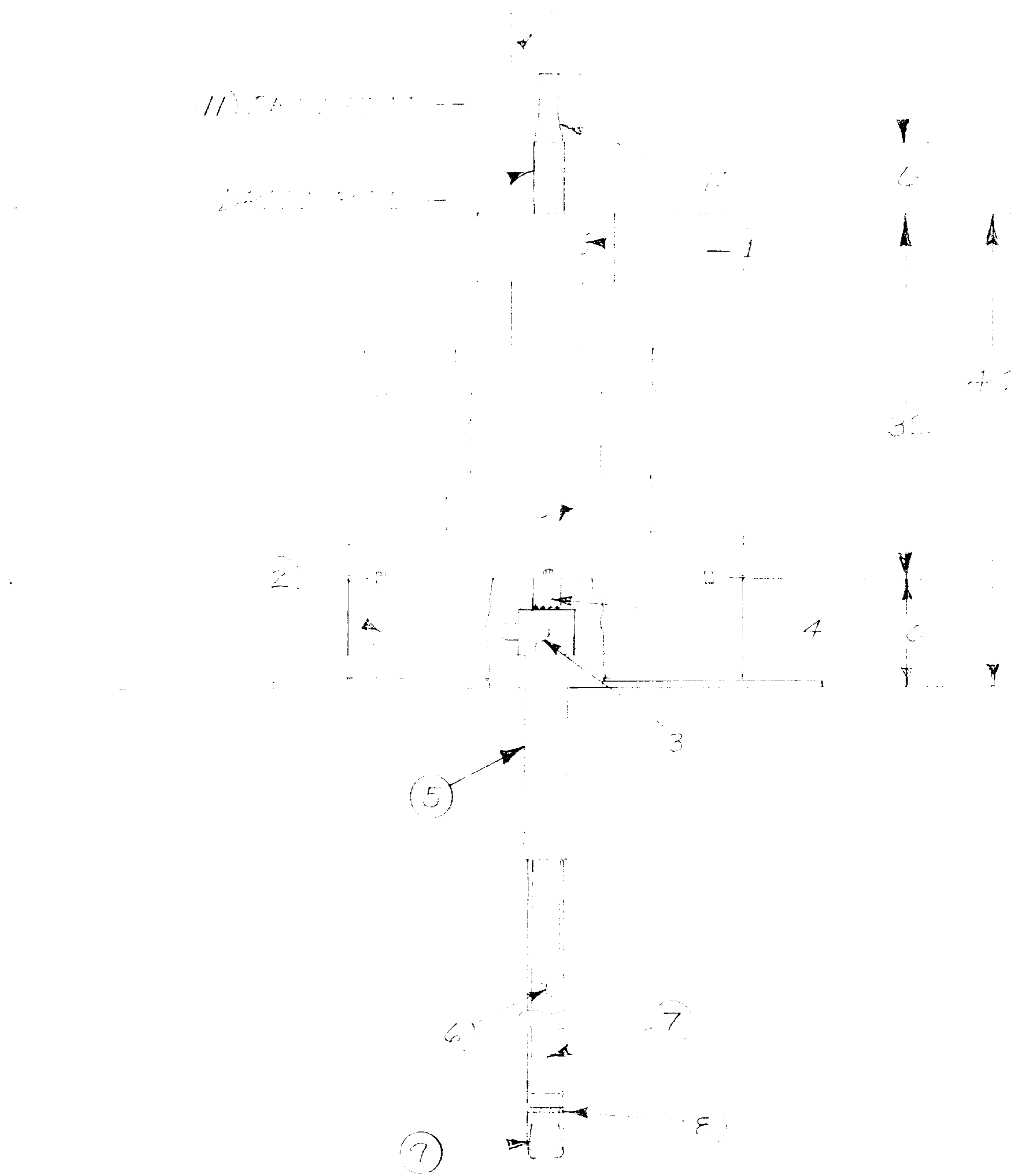


DRG NO	BORE SIZE	STRK	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	MODEL NO	DRG NO
117	5	40	42.6	[illegible]	1/2	1/2	3	6	6	1 1/2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	CRT-500	117
118	3	40	50.4	40.6	1/2	1/2	2	3 1/3	4 3/3	1 1/2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	CTR-300	118
119	2	20	30.4	[illegible]	1/2	1/2	1 5/8	3	3 1/8	1/2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/8	[illegible]	2	[illegible]	2	[illegible]	[illegible]	200	119
120	2	12	22.4	18	3/8	1/2	1 5/8	3	3 1/8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	200	120
121	2	10	20	[illegible]	3/8	1/2	1 5/8	3	3 3/8	1 1/2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	200	121

DWG NOS. 117-121

ENERGY HYDRAULIC CYLINDERS

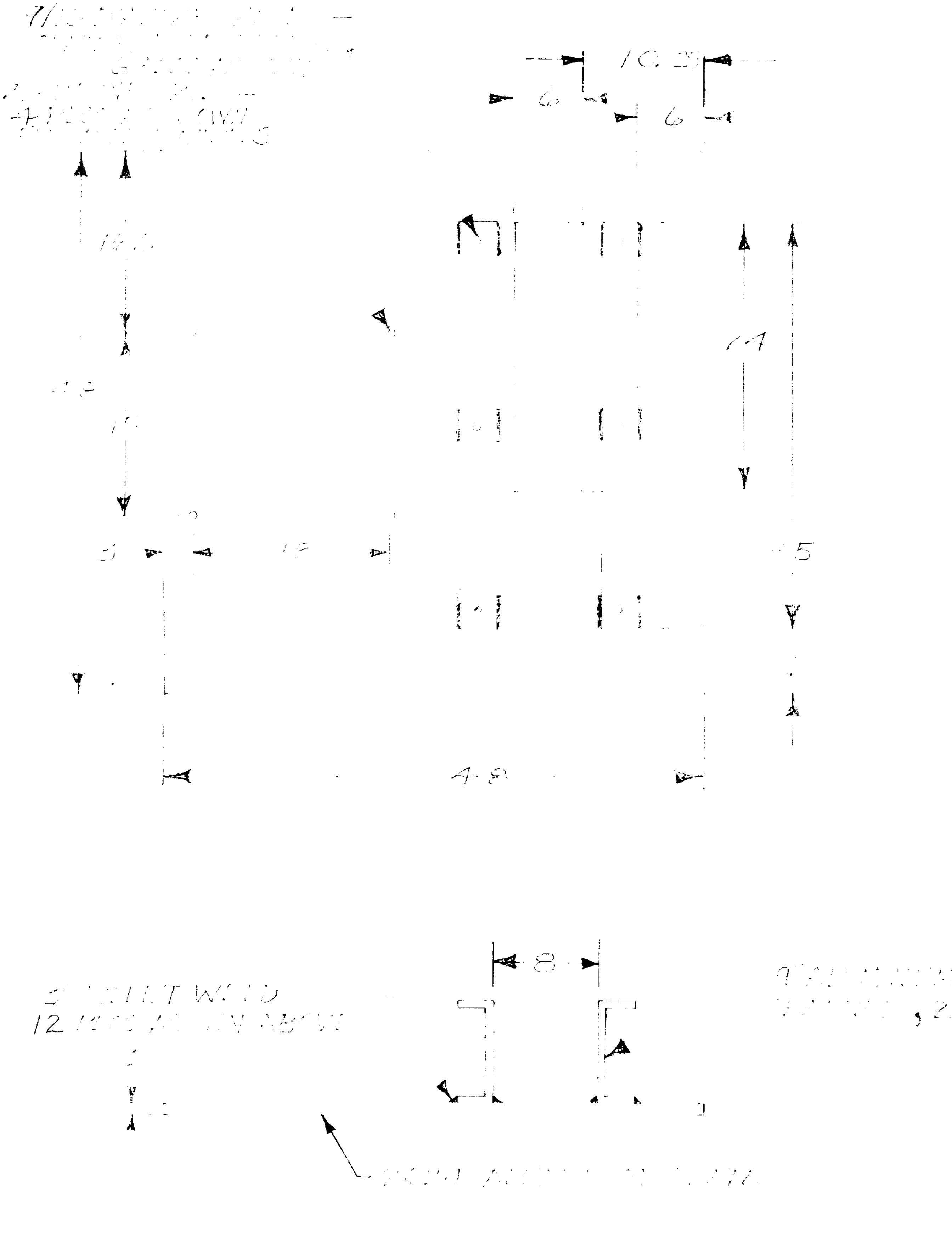
DRAWN BY NJC



DRILLING ...

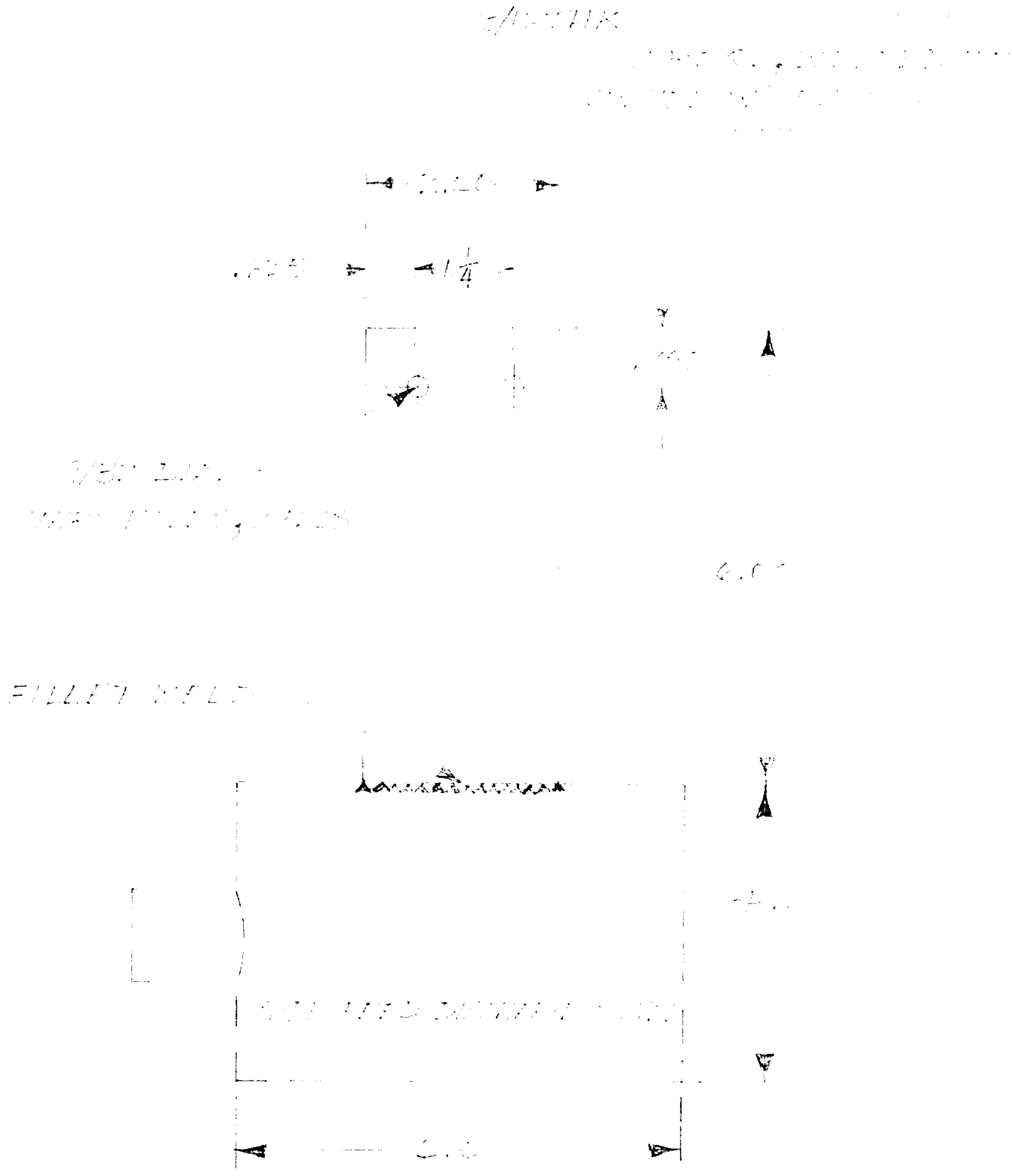
DWG NO. 20...

ORIGINAL PAGE IS
OF POOR QUALITY

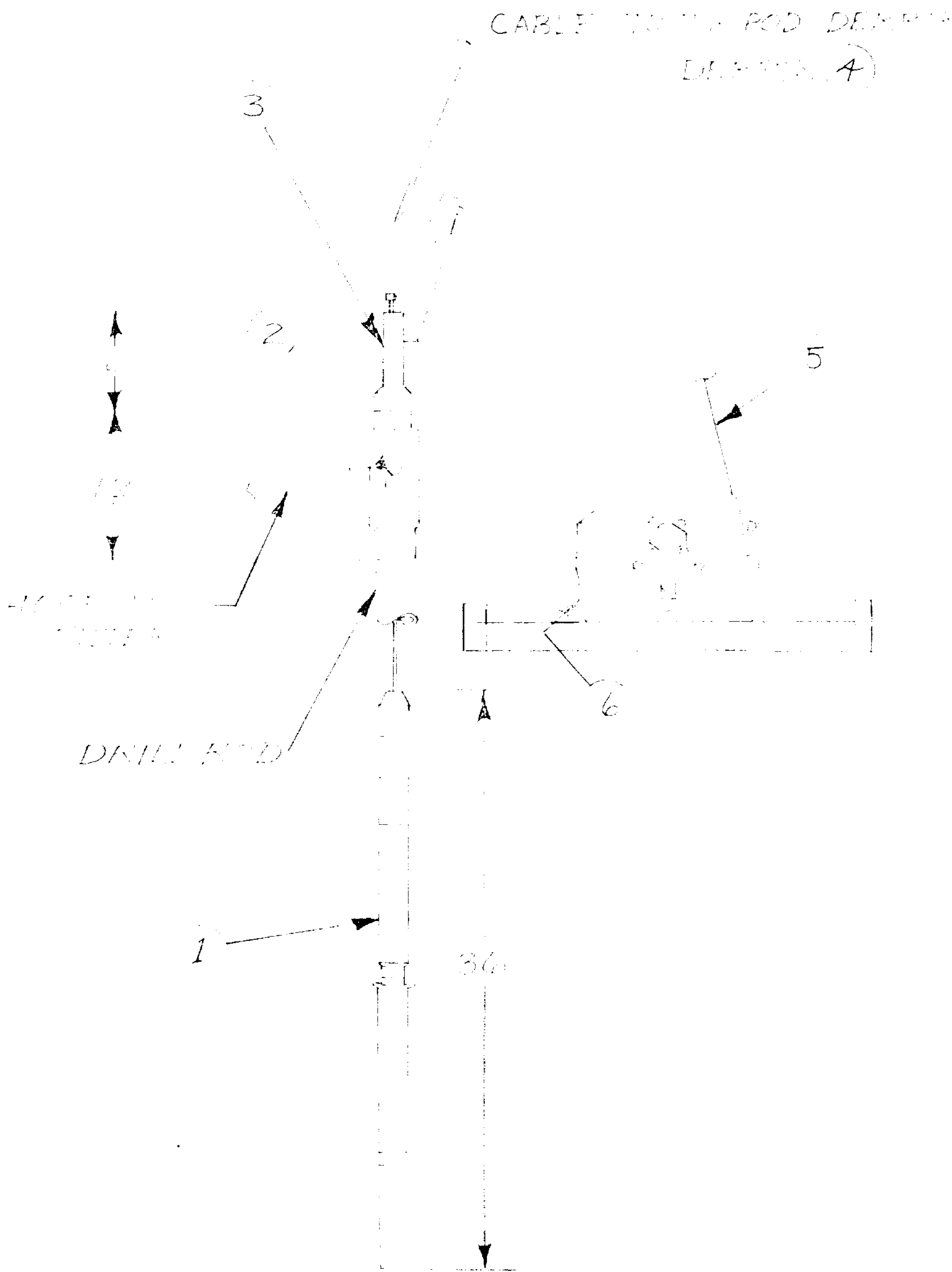


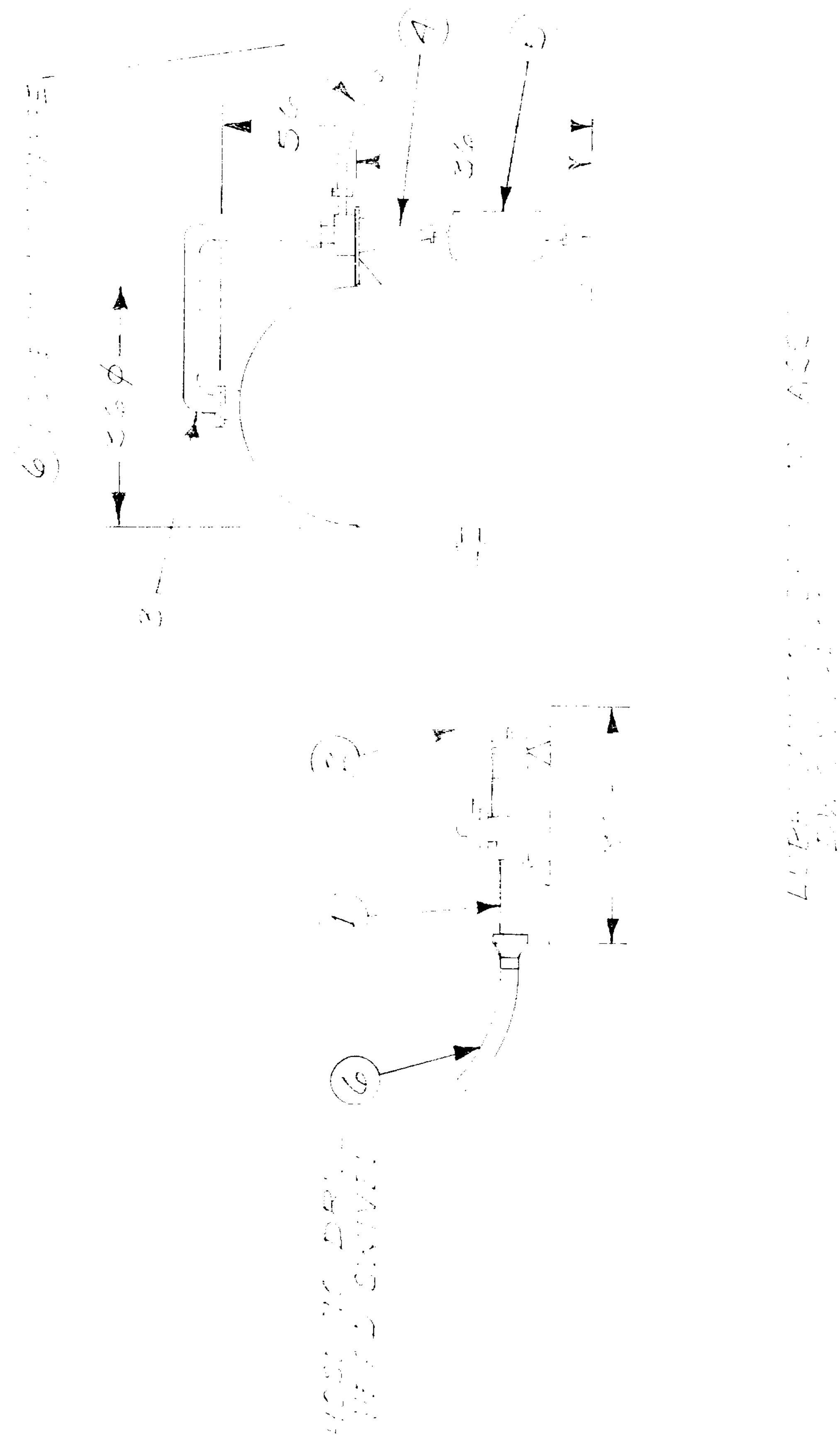
FOOT PLATE

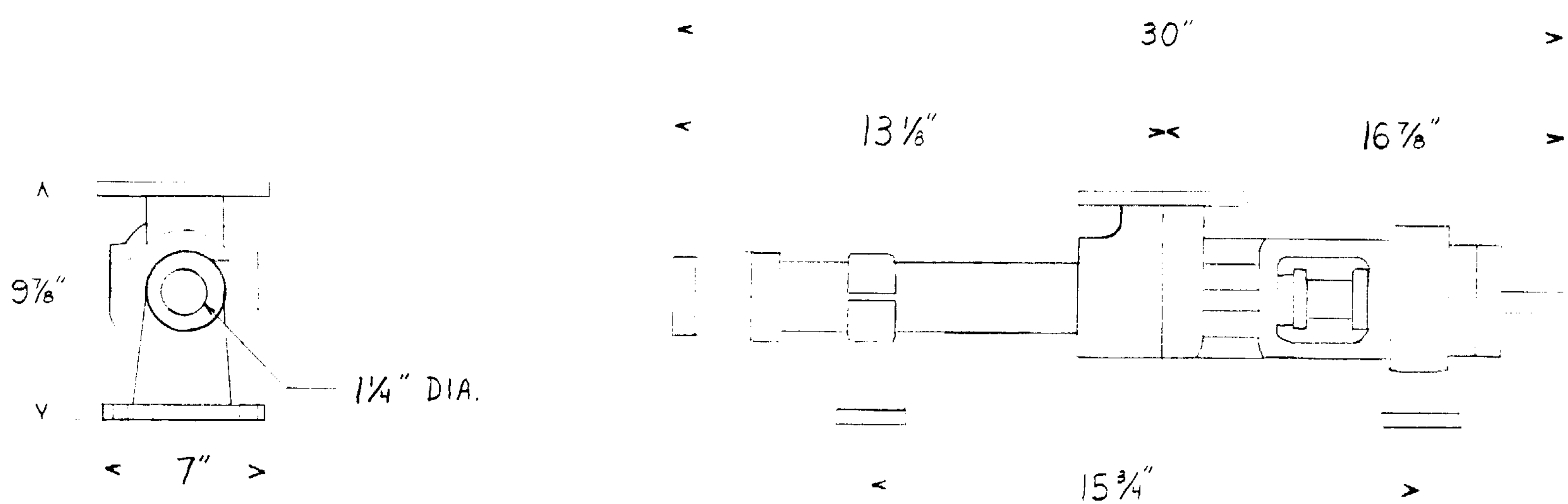
DWG NO. 201



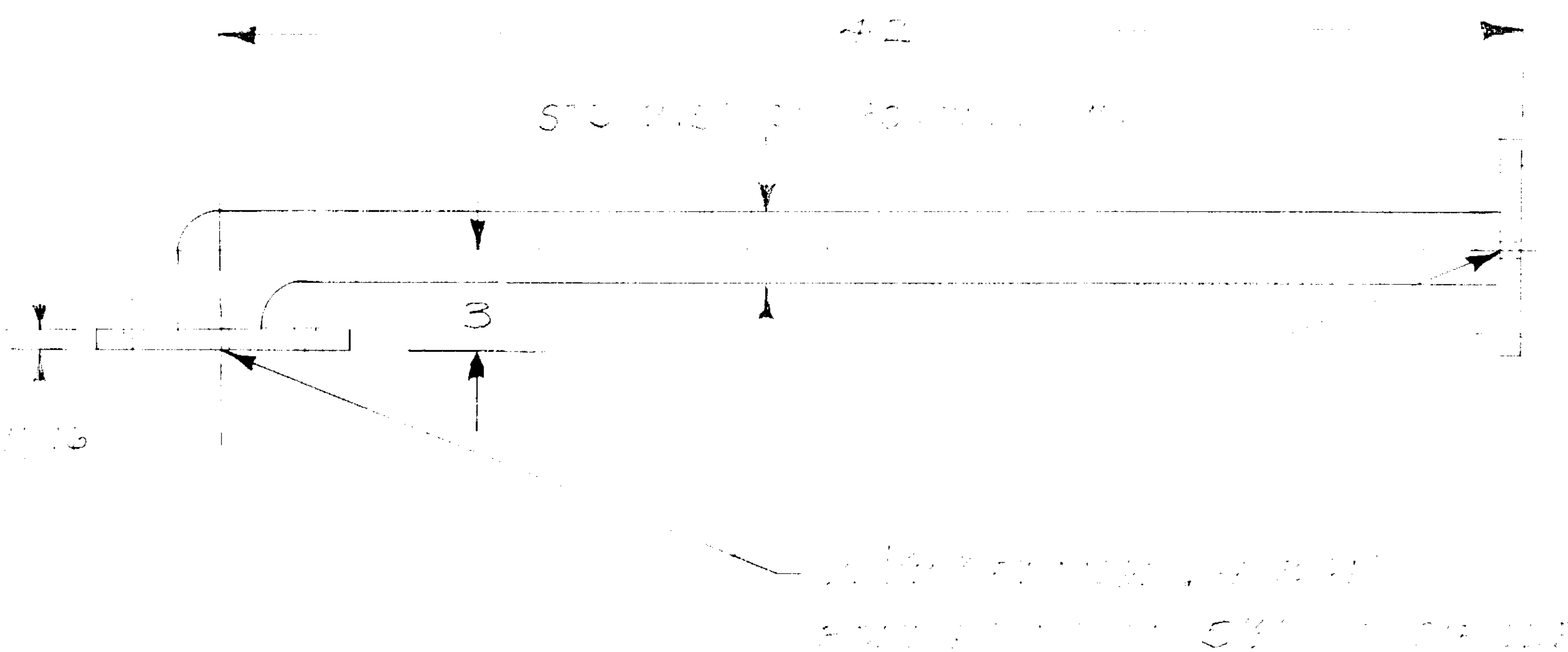
DWG NO. 202


CABLE
ROD
4
3
2
5
12
6
1
36

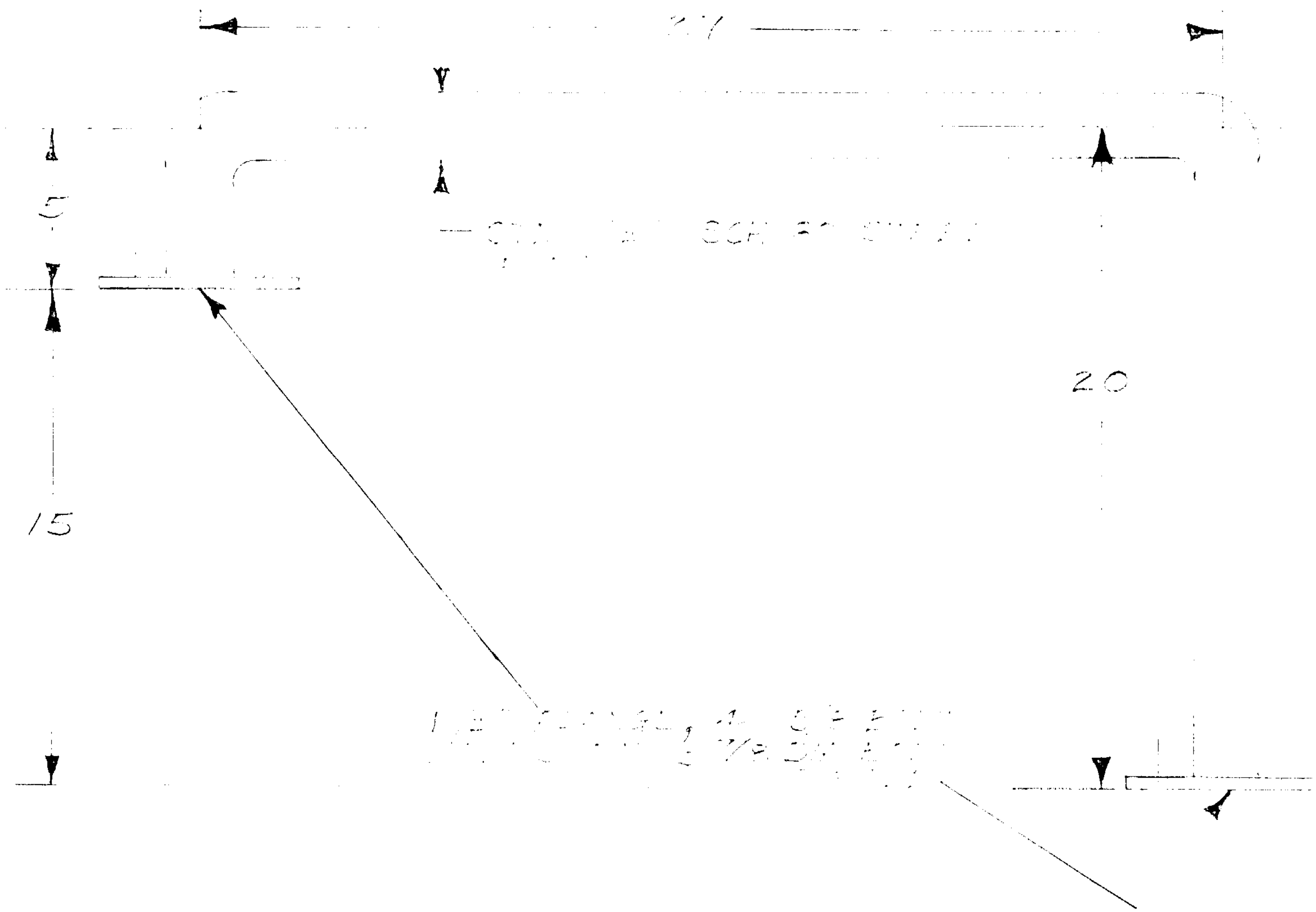




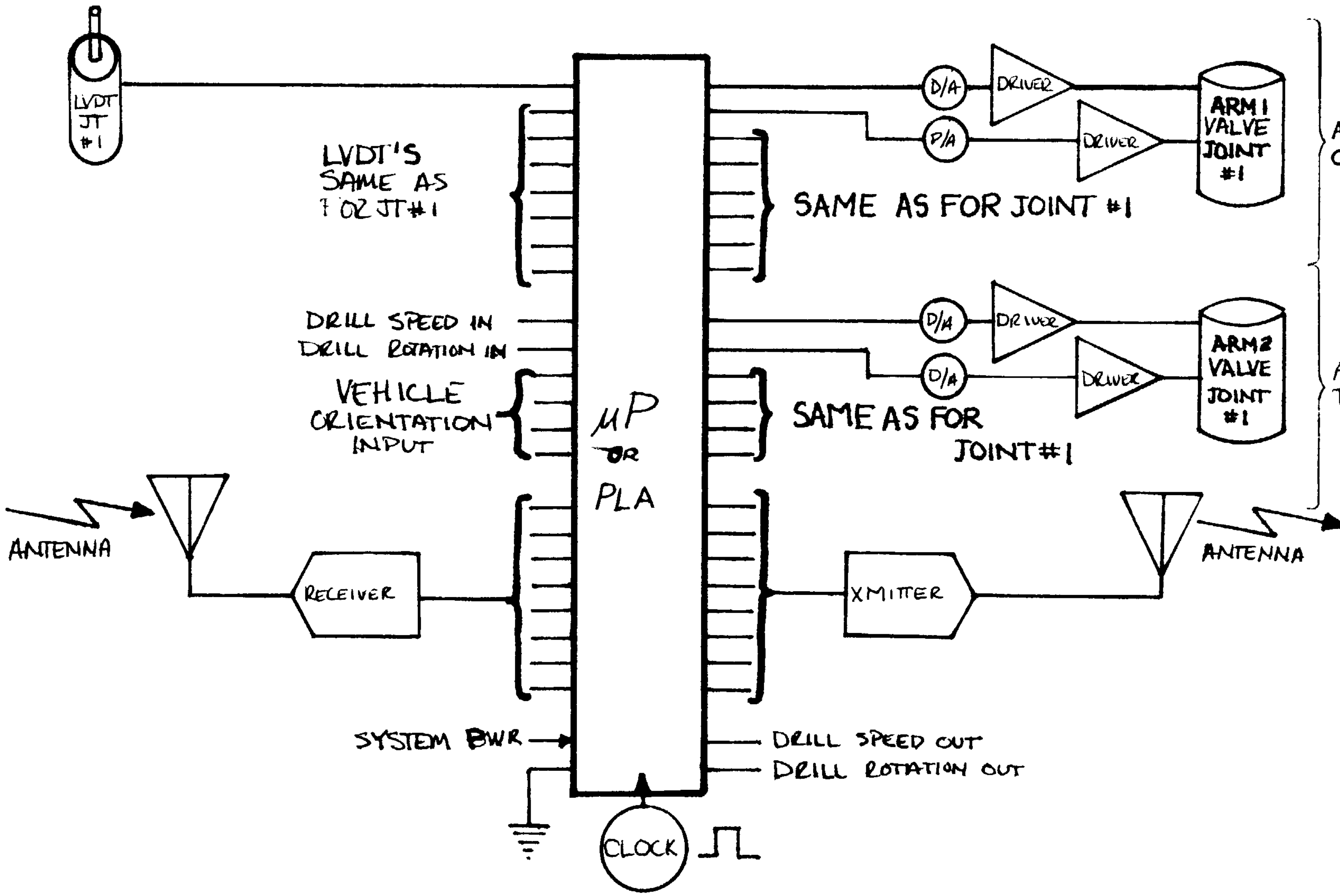
PROGRESSING CAVITY PUMP
DWG. NO. 4.61



TA[illegible] [illegible]TING P[illegible]
D[illegible] NO. 4[illegible]



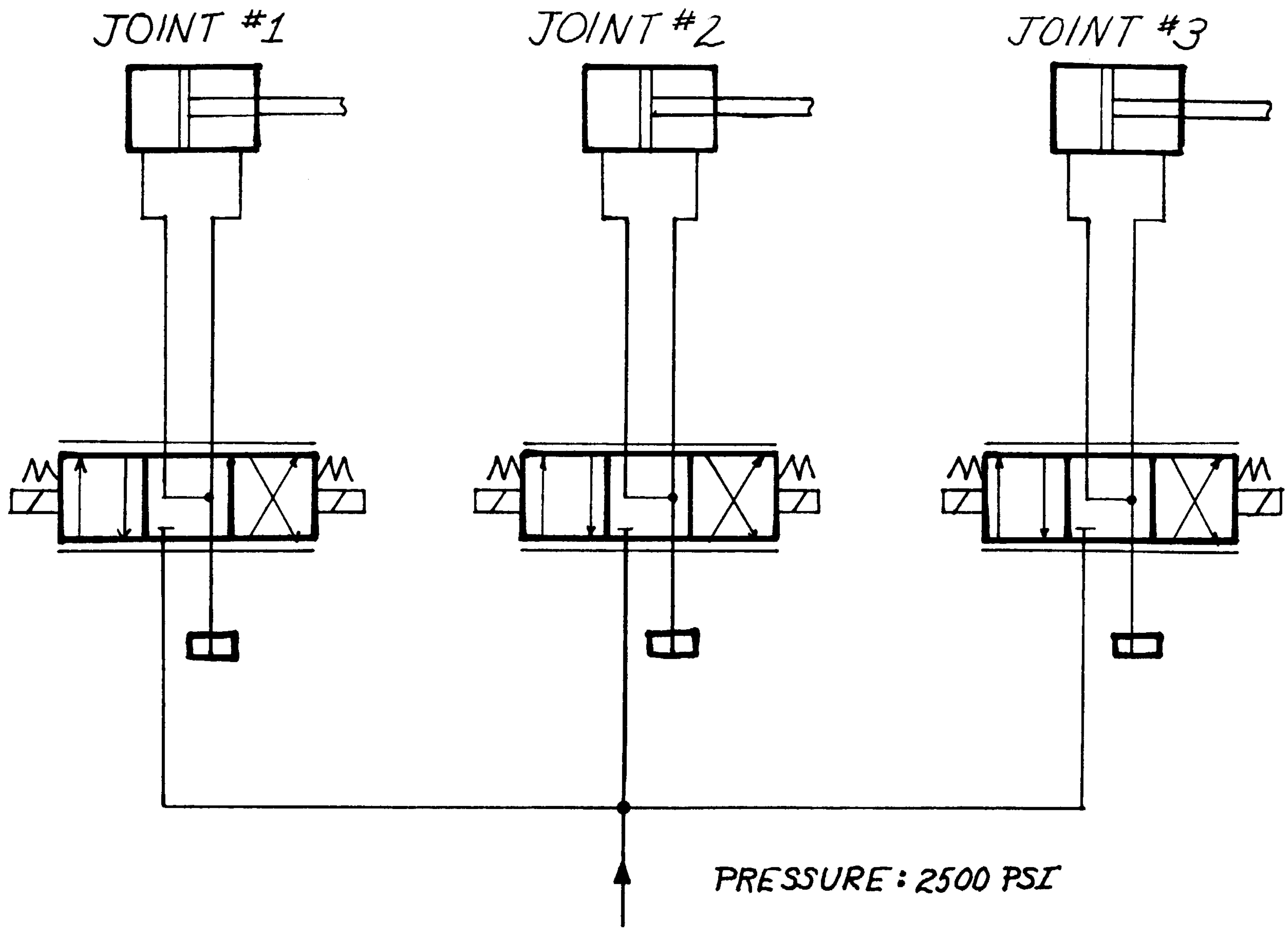
DWG NO. 403



CONTROL SYSTEM DIAGRAM

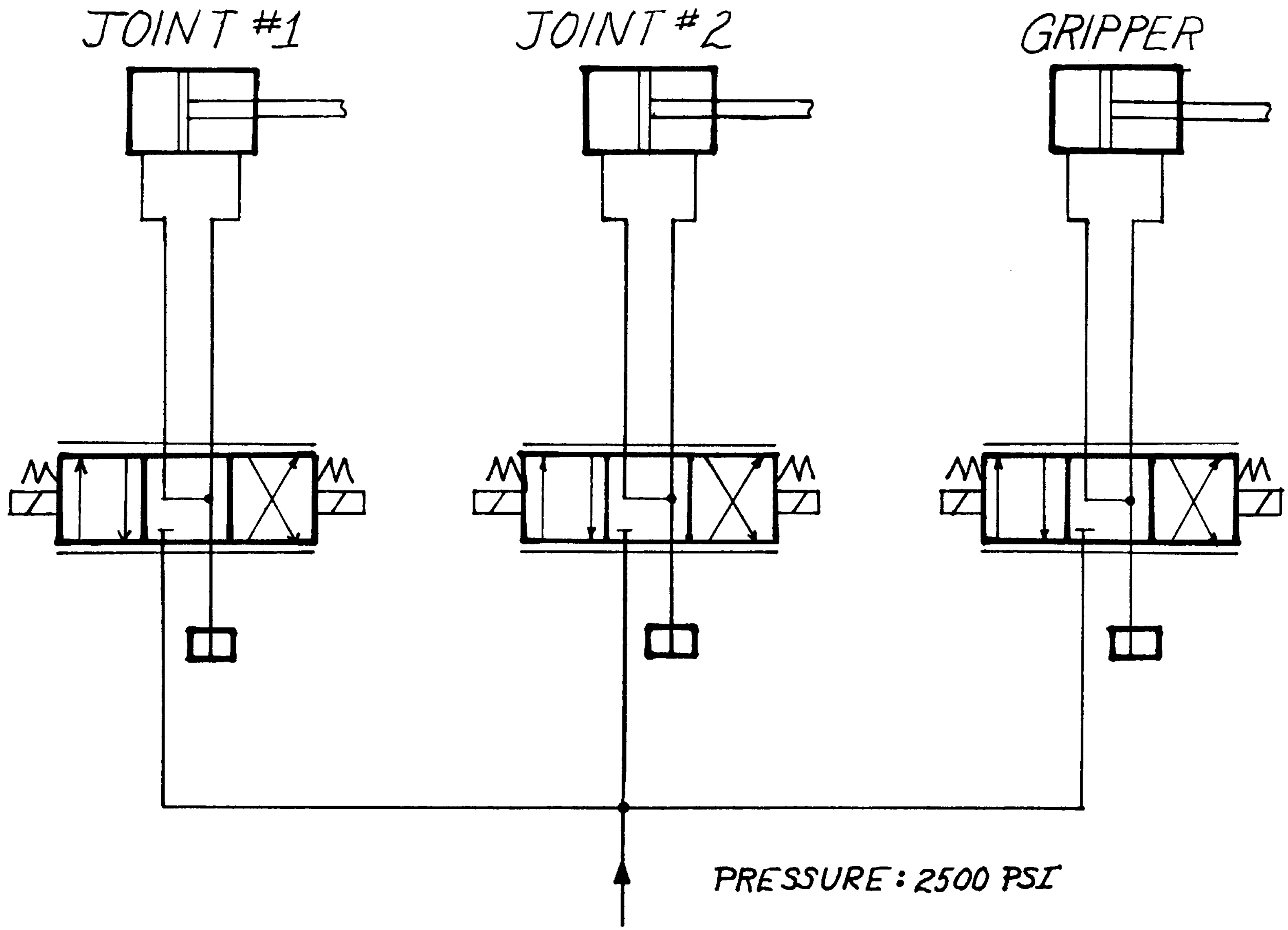
DWG 501

KCM



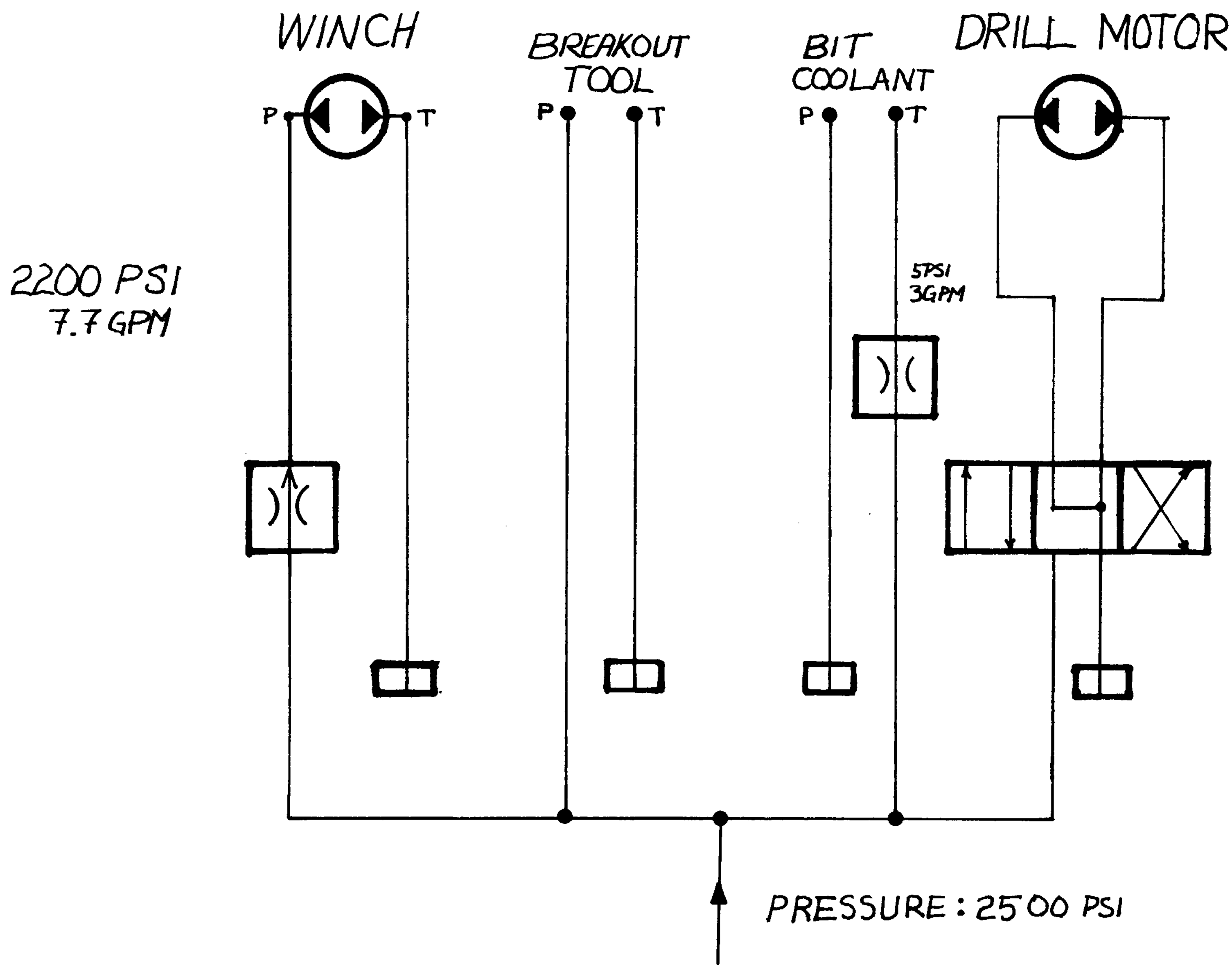
ARM #1 HYDRAULIC CIRCUIT
DWG 502

DRAWN BY : KOM



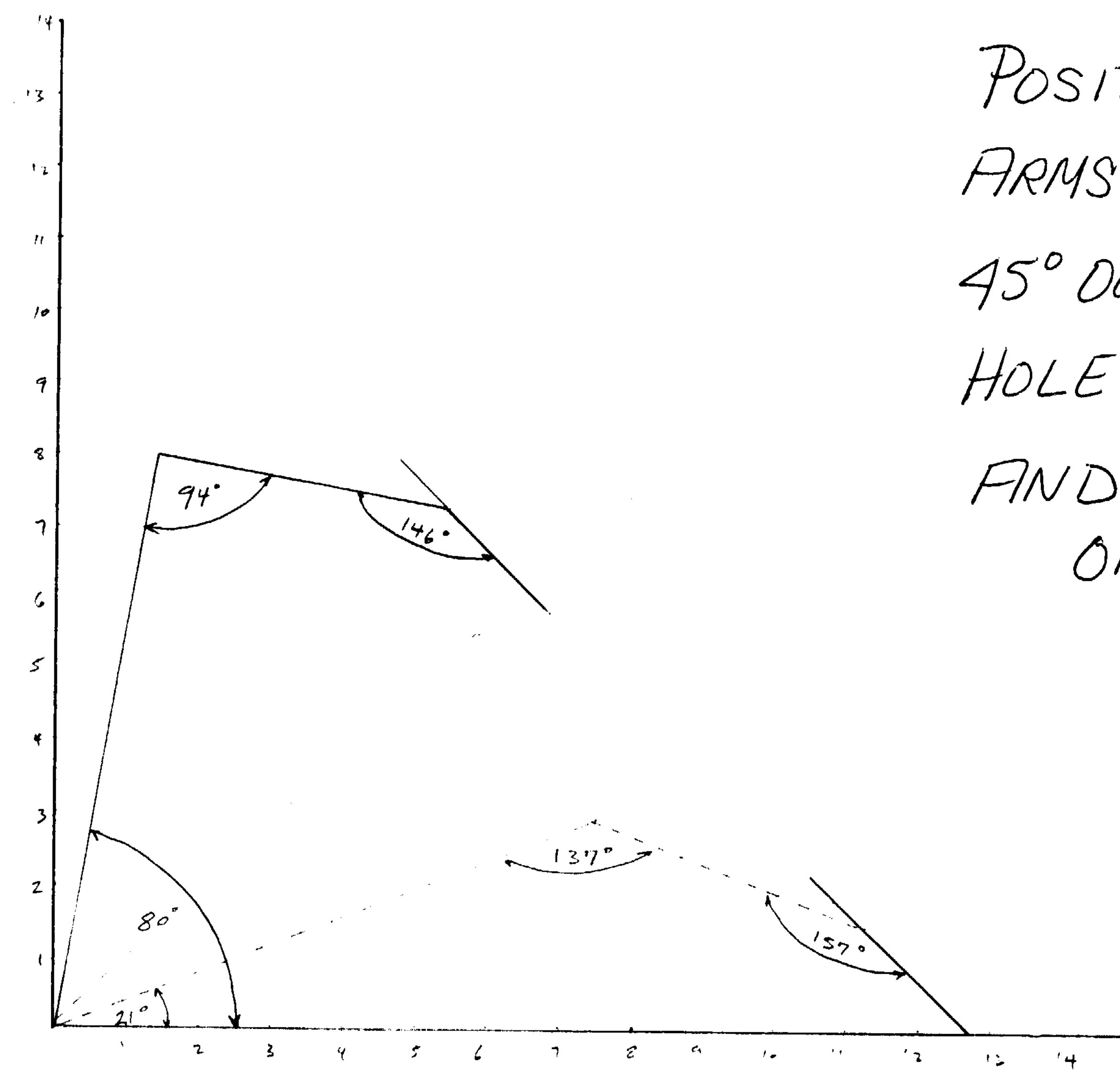
ARM #2 HYDRAULIC CIRCUIT
DWG 503

DRAWN BY: KOM

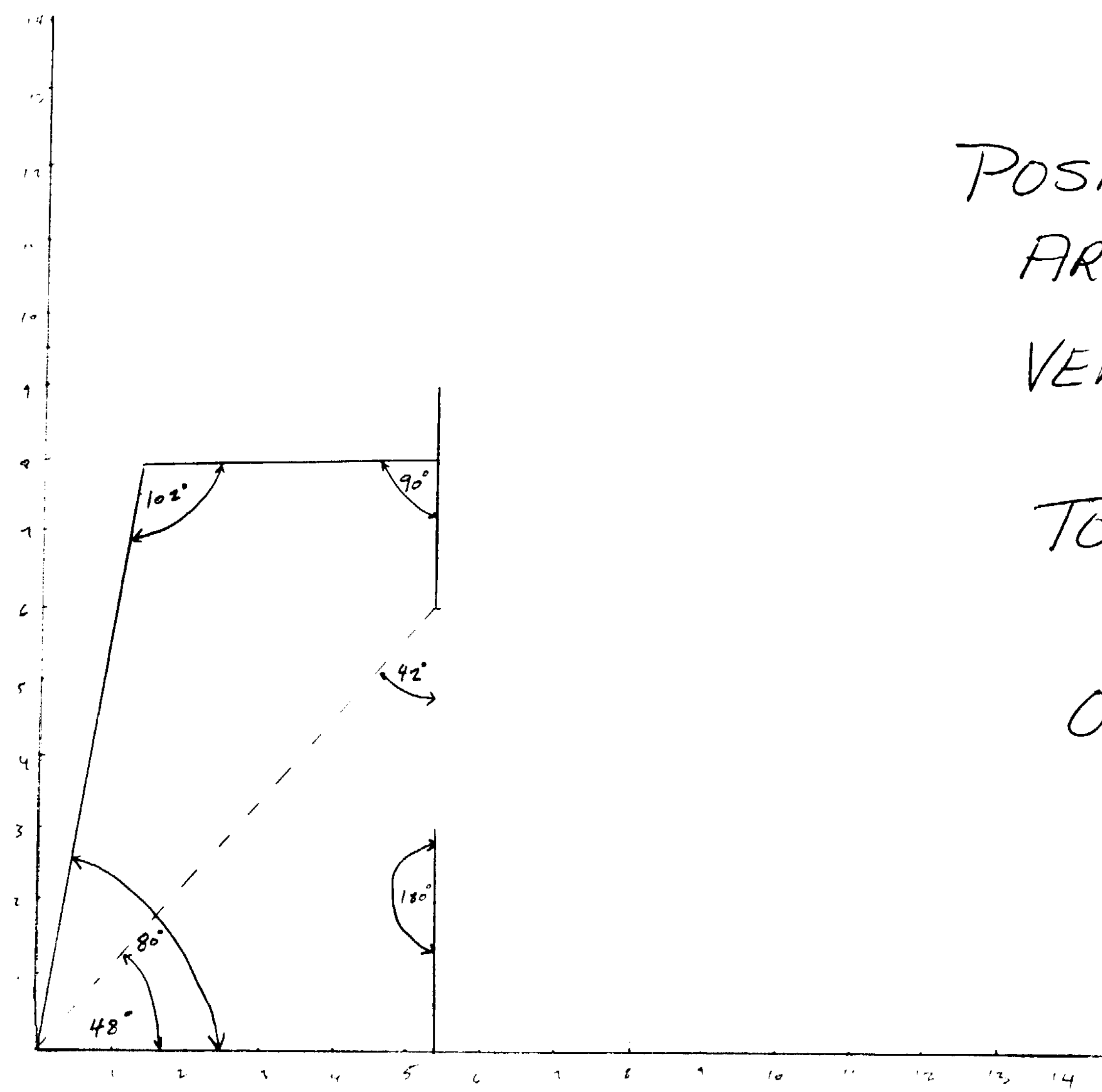


DRILLING CONTROLS
DWG 504

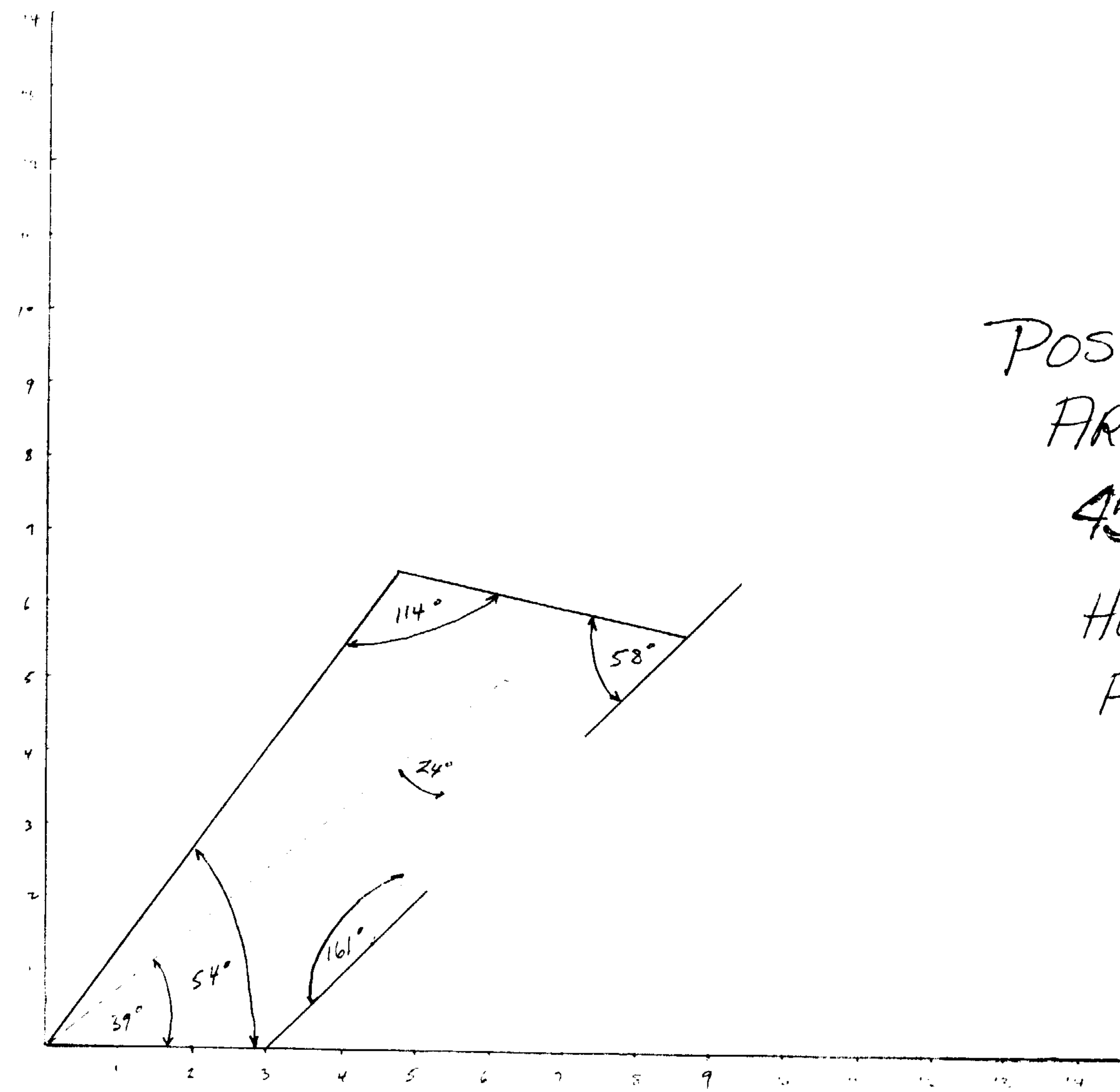
OPERATING POSITIONS OF THE ARM



POSITIONS OF ARMS FOR A 45° OUTWARD HOLE: TOP AND BOTTOM OF THE 5 FOOT STROKE



POSITIONS OF ARMS FOR A VERTICAL HOLE: TOP AND BOTTOM OF THE 5 FOOT STROKE

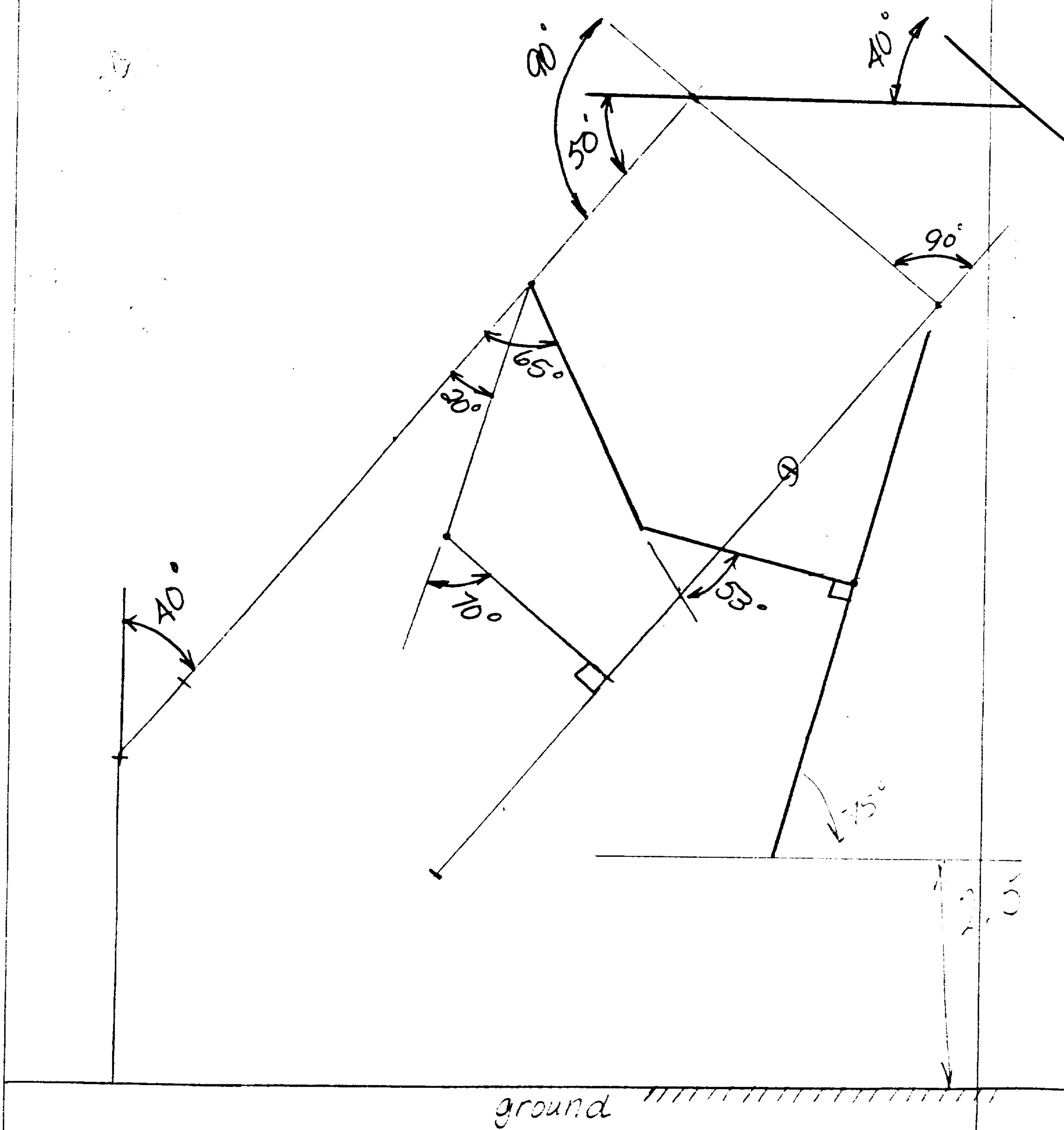


POSITIONS OF ARMS FOR A 45° INWARD HOLE: TOP AND BOTTOM OF THE 5 FOOT STROKE

Insert Position

Pick-up Position

POSITIONS OF ARMS TO ADD DRILL STRING PIECES



ALTERNATIVE DESIGNS

Despite all attempts, the design of the lunar core drill presented in this report may not represent the best solution possible. The following alternative designs are ones which were not evaluated extensively but may actually have contributed to a better overall solution.

Design of Arm

An alternative method for designing the arm would have been to simply use a Longyear Hydra Core 28 core drilling unit, mount it rigidly to a platform, and attack the platform to the tractor swivel. In this case, the platform or 'arm 'would only have to pivot in a horizontal plane and would not be required to form angles in a vertical plane. The Hydra Core 28, itself, would be capable of making the required 0 to 90 degree angles with respect to vertical and would supply its own downward hydraulic drilling force. Such a design would be simple compared to the 'backhoe' arm design and would require much lower hydraulic forces. Such a design, however, would not be able to function both as a core drill and a lunar excavator. At any rate, the design does seem promising.

Design of Lubrication System

As mentioned before, several ideas were considered and could be used as a future alternative design. Instead of using Teflon beads, a silicon-based oil might be substituted. The oil has a high maximum operating temperature and consistent viscosity at a variety of temperatures. However, the possibility of flashing would require a completely closed system which is difficult to design. Also, oil would leave a messy film on the sides of the hole that would restrict the use of a borescope. On the other hand, a conventional pump could be used and a less complicated filtering system could be designed. Whichever process is chosen, it must undergo much testing before its operation begins.

Another solution to this problem is to have no lubricant at all. In such a case, a dry hole would be drilled and augers on the end of the drill string would be used to collect the chips. Such a design has been experimented with before but has never worked flawlessly. The design is attractive, however, due to the fact that it requires no pump, no strainer system, and no evaporative or fluid loss considerations.

REASONS FOR NOT PURSUING LASER DRILLING

Drilling of lunar soil with a laser beam was suggested as an alternative to conventional, impractical methods such as a mechanical bit with a motor drive. It appears, from an overview of rock thermodynamics, that drilling of basalt with a laser may be possible with further research. All properties found were consistent with good thermal drilliability; abrasiveness makes mechanical drillibility difficult.

Some properties of basalt were found in various literature. A partial listing appears below:

Thermal conductivity [J/m sec C]	1.25 - 2.93
Heat capacity [J/g C]	0.63 - 0.90
Coefficient of linear expansion [1/CxE-5]	0.54
Modulus of Elasticity [kg/cm^2xE-5]	9.0 - 12.0
Poisson's ratio	0.24
Ultimate compressive strength [kg/cm^2]	300 - 400
Ultimate shear strength [kg/cm^2]	175 - 460
Melting Temperature [K]	1310
Texture	Fine grained, glassy

"The coefficients of linear and volume expansion of rocks are the most important thermo-physical characteristics governing their capacity to transform heat into mechanical energy."( )

$$\text{Coefficient of volume expansion} = \frac{wi\ Ki\ Vi}{Ki\ Vi}$$

where Ki = thermal conductivity of component i

Vi = volume of component i

wi = coefficient of thermal expansion of component i

These characteristics may be construed to prove that basalt is an excellent candidate for laser drilling. It melts rather than breaking, making removal from the hole by evaporation possible. Heat of vaporization data could not be located, so that problems of condensation could not be considered. A high heat of vaporization would make material removal easier.

The only reason for not considering the laser drilling option is the enormous power consumption of the laser, on the order of several kilowatts. This much power is not available in our design constraints. These design constraints should be reviewed and possibly changed in order to consider this option.

() Rzhevsky, Y. and Novik, G., (1971), The Physics of Rocks, Moscow: Mir Publishers, pp. 149, 285-290.

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"Diamond Drilling Equipment", Equipment Catalog, Longyear Company

ACKNOWLEDGEMENTS

Randy Klinger, Industrial Tectonics, Ann Arbor, Michigan (313) 426-4681

Joe Robinson, Sales Engineer, Clifton Plastics, (215) 622-3900

Terry Stachur, Tadco Systems, Atlanta, GA, (404) 972-6660

Linda Moeller, Dupont Technical Information Hotline-Teflon Products, 1-800-441-7515

Lynn A. Holmberg, Sales Service Technician-Central U.S.A.,925 Delaware Street S.E., Minneapolis, Minn. 55414, (612)-331-1331

RECORD OF INVENTION - Part I

This is an important legal document. Read instructions carefully before filling in data.

PROJECT NO.

CONTRACT NO.

RECOMMENDED SECURITY CLASSIFICATION

REC. OF INV. NO.

1. NAME OF INVENTOR: GEORGE PAUL BURDELL

POSITION: UNDERGRADUATE STUDENT

2. DEPARTMENT OR DIVISION: NONE

3. DATES OF EMPLOYMENT: NONE

4. PRESENT ADDRESS (No. Street, City, County, State): 225 NORTH AVENUE, ATLANTA, FULTON, GA

TELEPHONE: (404) 894-5051

PERMANENT OR UNTIL: PERMANENT

5. PERMANENT ADDRESS (No. Street, City, County, State)

TELEPHONE

6. NAMES (S) AND ADDRESS (ES) OF CO-INVENTORS (If any)

BARRY M. FRENCH - SAME
NANCY JEAN SHALER - SAME
MATTHEW L. ADAMS - SAME
MARK S. HAJOS - SAME
JAMES R. BROOM JR - SAME
KURT O. MONNIG - SAME

7. DESCRIPTIVE TITLE OF INVENTION

8. LIST DRAWINGS, SKETCHES, PHOTOS, REPORTS, DESCRIPTIONS, NOTEBOOK ENTRIES, ETC. WHICH SHOW OR DESCRIBE INVENTION

NONE

9. EARLIEST DATA AND PLACE INVENTION WAS CONCEIVED (Brief outline of circumstances)

ON 4 APRIL 1985, OUR GROUP CONCEIVED A LUNAR CORE DRILL TO AID IN SITE PREPARATION OF A LUNAR SPACE STATION.

10. DATE AND PLACE OF FIRST SKETCH, DRAWING OR PHOTO

4 APRIL 1985 ON THE 1ST FLOOR OF PRICE GILBERT MEMORIAL LIBRARY

11. DATE AND PLACE OF FIRST WRITTEN DESCRIPTION

SAME

12. DISCLOSURE OF INVENTION TO OTHERS

NAME, TITLE AND ADDRESS	FORM OF DISCLOSURE	DATE AND PLACE OF DISCLOSURE	WAS SIGNATURE OBTAINED (YES OR NO)
NONE			

12.A IMPORTANT - HAVE ANY PUBLICATIONS OR REPORTS BEEN MADE ON THIS INVENTION?

NO

13. DATE AND PLACE OF COMPLETION OF FIRST OPERATING MODEL OR FULL SIZE DEVICE

DOES NOT APPLY

14. PRESENT LOCATION OF MODEL

DOES NOT APPLY

15. DATE, PLACE, DESCRIPTION AND RESULTS OF FIRST TEST OR OPERATION

DOES NOT APPLY

16. NAMES AND ADDRESSES OF WITNESSES OF FIRST TEST

DOES NOT APPLY

17. DATE, PLACE, DESCRIPTION AND RESULTS OF LATER TESTS (name witnesses)

DOES NOT APPLY

18. IDENTIFY RECORDS OF TESTS AND GIVE PRESENT LOCATION OF RECORDS

DOES NOT APPLY

19. PRIOR REPORTS OR RECORDS OF INVENTION TO WHICH INVENTION IS RELATED

20. OTHER KNOWN CLOSELY RELATED PATENTS, PATENT APPLICATIONS AND PUBLICATIONS

PATENT OR APPLICATION NO.	DATE	TITLE OF INVENTION OR PUBLISHED ARTICLE	NAME OF PUBLICATION
NONE			

21. EXTENT OF USE: PAST, PRESENT AND CONTEMPLATED (Give dates, places and other pertinent details) NO APPARENT NEED AT THIS TIME, FUTURE USE WILL BE BY NASA PRIOR TO LUNAR CONSTRUCTION.

22. DETAILS OF INVENTION HAVE BEEN RELEASED TO THE FOLLOWING COMPANIES OR ACTIVITIES

NAME AND ADDRESS	INDIVIDUAL OR REPRESENTATIVE	CONTRACT NO.	DATE
NONE			

SIGNATURE OF INVENTOR George Paul Burdell DATE 2 June 1985

RECORD OF INVENTION - Part II

(Attach to Record of Invention Part I)

REC. OF INV. NO. ________________

This Disclosure of Invention should be written up in the inventor's own words and generally should follow the outline given below. Sketches, prints, photos and other illustrations as well as reports of any nature in which the invention is referred to, if available, should form a part of this disclosure and reference can be made thereto in the description of construction and operation.

1. INVENTORS NAME(S) GEORGE PAUL BURDELL
2. TITLE OF INVENTION LUNAR CORE-DRILLING APPARATUS

For answers to following questions use remainder of sheet and attach extra sheets if necessary.

3. GENERAL PURPOSE OF INVENTION. STATE IN GENERAL TERMS THE OBJECTS OF THE INVENTION.
4. DESCRIBE OLD METHOD(S) IF ANY, OF PERFORMING THE FUNCTION OF THE INVENTION.
5. INDICATE THE DISADVANTAGES OF THE OLD MEANS OR DEVICE(S).
6. DESCRIBE THE CONSTRUCTION OF YOUR INVENTION, SHOWING THE CHANGES, ADDITIONS AND IMPROVEMENTS OVER THE OLD MEANS OR DEVICES
7. GIVE DETAILS OF THE OPERATION IF NOT ALREADY DESCRIBED UNDER 6.
8. STATE THE ADVANTAGES OF YOUR INVENTION OVER WHAT HAS BEEN DONE BEFORE.
9. INDICATE ANY ALTERNATE METHODS OF CONSTRUCTION.
10. IF A JOINT INVENTION, INDICATE WHAT CONTRIBUTION WAS MADE BY EACH INVENTOR.
11. FEATURES WHICH ARE BELIEVED TO BE NEW.
12. AFTER THE DISCLOSURE IS PREPARED, IT SHOULD BE SIGNED BY THE INVENTOR(S), AND THEN READ AND SIGNED AT THE BOTTOM OF EACH PAGE BY TWO WITNESSES USING THE FOLLOWING STATEMENT: "DISCLOSED TO AND UNDERSTOOD BY ME THIS______DAY OF_________19___ SIGNATURE_____________________________."

THE PURPOSE OF SAID INVENTION IS TO OPERATE AS A CORE-DRILLING MECHANISM UNDER LUNAR CONDITIONS. THIS MACHINE MUST BE ABLE TO WITHSTAND LOW PRESSURES AND HIGH TEMPERATURES, YET BE OPERABLE BY AN AUTOMATED SYSTEM.

EXISTING TECHNOLOGY IS LIMITED TO EARTH-BOUND EQUIPMENT. THIS GENERAL METHOD INVOLVES THE USE OF WATER AS A LUBRICANT, COOLANT, AND MEANS OF REMOVING THE CHIPS FROM THE BOTTOM OF THE HOLE. ANOTHER CHARACTERISTIC OF PRESENT EQUIPMENT IS ITS MOUNTING ON A TRAILOR WHICH PERMITS EASY MOBILITY. THE PROCEDURE BEGINS WITH THE DRILL PROGRESSING DOWNWARD WHILE THE WATER IS PUMPED INTO THE CENTER OF THE STRING. BY PASSING THROUGH THE TEETH OF THE BIT, THE WATER COLLECTS THE SHAVINGS AND CARRIES THEM UPWARD ALONG THE OUTSIDE OF THE SHAFT. GENERALLY, THIS MIXTURE IS ALLOWED TO SPREAD OVER THE GROUND

DUE TO THE INFEASIBILITY OF EXTRACTING THE WATER. WHEN AN ADDITIONAL LINK IS NEEDED, THE PROCESS STOPS AND CREWMEN MANUALLY JOIN THE NEW PIECE.

REC. OF
INV. NO. ______________

DISADVANTAGES OF THIS EXISTING SYSTEM ARE:

1. WATER CAN NOT BE USED IN THE LUNAR ENVIRONMENT BECAUSE IT WOULD VAPORIZE DUE TO THE LOW PRESSURE; THEREFORE ANY LIQUID LUBRICANT OR COOLANT WOULD HAVE TO OPERATE IN A COMPLETELY CLOSED SYSTEM.

2. AUTOMATIC CONTROLS MUST MONITOR ALL EQUIPMENT BECAUSE OF THE INABILITY TO "SENSE" HOW A PART IS OPERATING. ALSO, MANUAL LABOR IS NOT PRACTICAL BECAUSE OF THE BULKY SPACE SUITS WHICH RESTRICT MOST MOVEMENT.

TO MAKE A CORE DRILL SUITABLE FOR LUNAR OPERATION, SEVERAL CHANGES WERE MADE. FIRST, SOLID TEFLON BEADS WERE SUBSTITUTED FOR WATER, THUS AVOIDING THE POSSIBILITY OF FLASHING. THE BEADS WILL BE HANDLED SIMILARLY TO WATER EXCEPT A COMPLEX FILTERING SYSTEM WILL BE ADDED. SECONDLY, ALL MACHINES WILL BE INTERCONNECTED THROUGH AN AUTOMATIC CONTROL NETWORK. THE ASTRONAUT WILL THEN BE ABLE TO MONITOR THE ENTIRE SYSTEM FROM A CENTRAL POST. FINALLY, THE CORE DRILL OPERATES SIMILARLYTO A BACKHOE ARM. BECAUSE SPACE VITAL ON A MOON PROJECT, THIS VERSATILITY PERMITS ONE TRACTOR TO BE USED FOR SEVERAL DIFFERENT FUNCTIONS.

THE LUBRICATION / COOLANT SYSTEM BEGINS WITH THE TEFLON BEADS BEING PUMPED BY A PROGRESSING CAVITY PUMP DOWN THE CENTER OF THE SHAFT. ONCE AT THE BOTTOM, THE BEADS PASS THROUGH THE DIAMOND DRILL BIT AND PICK UP THE SHAVINGS CREATED. THIS MIXTURE CONTINUES UPWARD WHERE IT ENTERS A CENTRIFUGAL FILTER AFTER REACHING THE SURFACE. CENTRIFUGAL FORCES MOVE

George Paul Burdell INVENTOR 2 June 1985	DISCLOSED TO AND UNDERSTOOD BY ME ON THIS 2 DAY OF June 1985 Mark S. Dejes WITNESS	DISCLOSED TO AND UNDERSTOOD BY ME ON THIS 2 DAY OF June 1985 Nancy Johnson WITNESS

THE LIGHTER BEADS OUTWARD WHERE THEY PASS ON THROUGH THE SYSTEM WHILE THE HEAVIER DIRT PARTICLES DROP TO A TANK. AFTER THE FILTER, THE BEADS RETURN TO THE PUMP WHERE THE PROCESS CONTINUES.

THE MOST ORIGINAL IDEA IMPLEMENTED INTO THIS CORE DRILL IS THE USE OF TEFLON BEADS. TEFLON, DEVELOPED BY DUPONT, IS JUST BEGINNING TO BE USED IN THE BEAD FORM. ALTHOUGH EXPENSIVE TO PRODUCE, THE BEADS WITHSTAND THE HIGH TEMPERATURES AND OFFER CONSTANT VISCOSITY FOR THE SYSTEM.

George Paul Burdell
INVENTOR
2 June 19 85

DISCLOSED TO AND UNDERSTOOD BY ME ON THIS 2 DAY OF June 19 85
Mark S. Hogus
WITNESS

DISCLOSED TO AND UNDERSTOOD BY ME ON THIS 2 DAY OF June 19 85
Nancy J. Phalen
WITNESS

REFERENCES

1. Karol R. E., Engineering Properties of Soils, NY, Prentice Hall (1955)

2. Das M. B., Introduction to Soil Mechanics, The Iowa State University (1979)

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